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TERTIARY TREATMENT BY FLOCCULATION AND RAPID-SAND FILTRATION

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Dayton Department of Water
Dayton, Ohio

May 1969

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A Demonstration Project Performed by the Division of Sewage Treatment, Department of Water, City of Dayton, Ohio

Partially Supported by the Federal Water Pollution Control Administration, Grant WPD-114

May, 1969

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A Demonstration Project by
the City of Dayton, Ohio,
In Part Financed by FWPCA
Demonstration Grant WPD-114

MAY 1969

STUDIES AND REPORT

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ABSTRACT

This report has been prepared to indicate progress on demonstration work which was supported in part by Federal Water Pollution Control Administration Demonstration Grant WPD-114. The report summarizes work performed by the City of Dayton from May 1966 to April 1969.

The goal of the project was to develop methods for achieving a high level of treatment in a large municipal wastewater treatment plant. The high level of treatment would be necessary to meet effluent objectives compatible with the receiving stream standards for the Miami River. The conventional water treatment processes of flocculation, sedimentation, and rapid-sand filtration were studied in a 0.5 MGD pilot plant to demonstrate their applicability in tertiary treatment following high rate trickling filter secondary treatment.

Work to date has demonstrated that the quality of effluent from a large municipal wastewater plant utilizing high rate trickling filter secondary treatment can be significantly improved by employing water supply treatment principles in tertiary treatment. Lime and alum have been used as primary coagulants assisted in settling by activated silica, ferric sulfate, and an organic polyelectrolyte. Suspended solids, BOD, and phosphates have been significantly reduced.

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GOALS AND EXPERIMENTAL RESULTS

The goal defined for this study was to demonstrate on a semi-works basis the feasibility of tertiary treatment by chemical coagulation, flocculation, sedimentation, and rapid-sand filtration at a large municipal trickling filter plant. Treatment removals of approximately 85% of BOD and suspended solids have been achieved, as annual averages. Severe overloading of the secondary plant in recent years has dropped these efficiencies. Indications are that to meet receiving stream quality criteria, 90% to 95% BOD and suspended solids removals would have to be maintained combined with phosphate removal.

It is projected that with renovation of the secondary plant (currently underway) BOD and suspended solids removals will be in the ranges of 85% to 90% and, therefore, the above goals could not be met. Furthermore, the existing plant provides very little phosphate removal, which is currently recognized as the key to algae control in the receiving stream.

Of primary consideration in development of the demonstration facility and future plant planning was maximum utilization of existing plant facilities. It was determined that the application of the water treatment methods of chemical treatment in flocculation and settling followed by rapid-sand filtration would readily lend itself to integration with existing facilities. A demonstration plant incorporating these methods was constructed

to test and evaluate the enhanced removals that could be achieved with various chemical combinations on unsettled trickling filter effluent.

Experimental results have shown that alum and lime as primary coagulants, assisted in settling with flocculant aids, can provide a high degree of treatment in settling alone and that rapid-sand filtration further enhances the quality of the effluent, within the limits of the tests. High levels of phosphate removals can be achieved in settling with both alum and lime. Evaluation of a dual media filter using 20 inches of coarse anthracite and 10 inches standard filter sand gave better overall performance than a filter using 30 inches of standard filter sand.

When chemically treating a poor quality trickling filter effluent, it was possible to consistently provide an overall plant BOD reduction of 88% in settling and 94% when followed by rapid-sand filtration. Suspended solids reductions with chemical treatment could be maintained at 89% in settling and 95% when followed by rapid-sand filtration treating a poor quality trickling filter effluent. Phosphate removals of up to 99% have been achieved and phosphate removals of 90%+ appear to be attainable on a year-round basis. It is anticipated that when secondary plant renovation is complete, higher BOD and suspended solids removals can be attained with less chemicals

than herein reported.

Chemical treatment facilities in settling as adapted to the existing treatment works would cost approximately $8.20 per million gallons to own and operate on a year-yound basis exclusive of chemicals. Chemical costs would vary with the degree of treatment desired. Rapid-sand filtration would cost approximately $21.20 per million gallons to own and operate on a year-round basis. Based on work to date it appears that rapid-sand filtration preceeded by plain settling does not provide an economic alternative to chemical treatment in settling, but may be used to provide a final polish not attainable in chemical treatment and settling alone.

BACKGROUND

Miami River

The City of Dayton, Ohio, is located on the Miami River and is the heart of the Miami River watershed. The metropolitan area has a population of 600,000, making it the 39th largest metropolitan area in the United States. Dayton is a world leader in the production of many commodities. It is an international center of precision industry. The 1100 manufacturing establishments in the metropolitan area alone employ over 127,000 people and in 1968 produced goods with a total value of over one billion dollars.

The Miami River drains an area of 5385 square miles, 3950 in southwestern Ohio and 1435 in eastern Indiana. The valley is approximately 165 miles long. Dayton lies at the heart of the valley, approximately 80 miles from the mouth of the river. Records from a gauging station below Dayton show flow varying from a minimum of 100 cfs to a maximum of 352,000 cfs, with an average flow of 3,143 cfs. The Miami River is characterized by a flashy hydrograph, presence of pools behind a number of low level dams, recirculation of large volumes of river flow for cooling at power generating stations, and diversion of flow to hydraulic canals below Dayton. Population of the basin is estimated at 1,500,000.

Heavy concentration of industry and population has necessitated high effluent standards for all wastewater discharges. Indeed, the Ohio Department of Health has long realized the need for proper wastewater control and began in the 1920's to work toward adequate treatment of all municipal and industrial discharges.

A 1966 engineering study of the Miami River, commissioned by the Miami Valley Water Quality Committee, found that the reach of stream below Dayton was polluted with organics and inorganics, heat, color, and metal plating wastes. This report draws the conclusion that to reach the quality level designated Aquatic Life "B" as defined by the Ohio Water Pollution Board (see Appendix B) in the river below Dayton, it would be necessary to:

1. Provide 85% to 90% BOD removal combined with algae control, low flow augmentation, or in-stream aeration, and distribute Dayton's effluent over a large reach of the stream; or
2. Provide 90% to 95% BOD removal and algae control.

This report concluded that the sluggish nature of the stream below Dayton and the dense industrialization make it very doubtful that higher objectives can be met. However, the water quality standards set by the Ohio Water Pollution Control

Board call for implementation of Aquatic Life "A" (see Appendix B).

The Dayton Sewage Treatment Plant

Dayton city officials, long realizing the importance of waste treatment to the well-being of the Miami River, constructed the original Dayton Sewage Treatment Plant in 1929. Since then the plant has been continually expanded and upgraded to meet the water quality objectives set by the Ohio Department of Health.

Dayton's wastewater is a combination of domestic and industrial discharges. The sources of industrial wastes include a number of large and small machine shops, manufacturing operations, metal plating plants, one bond paper manufacturer discharging 1500 gpm of wastewater, several large meat packing houses, two industrial laundries, numerous small lime-soda ash and ion exchange industrial water softening systems, two soap factories, and many others.

In 1965 discharges from metal plating plants resulted in cyanide concentrations of 1.0 mg/l in the raw wastewater, but has gradually tapered to 0.70, 0.51, and 0.39 mg/l in 1966, 1967, and 1968 respectively. Peaks have exceeded 2.0 mg/l on 24 hour composites. The gradual tapering off is probably due to development of non-cyanide plating processes. Virtually

all of the cyanide reduction in the wastewater treatment process occurs on the trickling filters. Hexavalent chrome has averaged 0.84 mg/l on 24 hour composites over the last two years with the highest level observed at 3.1 mg/l. There is some removal through the plant but it is not consistent. Other metals, including cadmium, copper, zinc, tin, and lead, are found in the plant influent.

Greases and oils are a significant portion of plant influent, including "biodegradable" machine shop cutting oil solutions and possibly motor oil from such sources as automobile service stations. Laboratory analyses of cutting oil samples have demonstrated that BOD's of over 3,000 mg/l might be exerted. In addition, there is considerable grease discharged by industrial laundries and meat packing establishments.

The city has no firm industrial waste policy except to furnish maximum practical service to the customer. Thus far, the city has successfully operated under this policy and has not found it necessary to enact an industrial waste ordinance regulating or restricting discharge of certain wastes. Relations with sewer service customers are such that when wastewater problems occur, they can usually be settled on an amicable basis. The city carries out no regular inspection to maintain a complete inventory of industrial wastewater discharges.

In 1967 and 1968 total phosphate (as PO_4) in the plant influent averaged 35.2 mg/l and 33.2 mg/l in the effluent. Most of the polyphosphate entering the plant is hydrolyzed to orthophosphate in the treatment process. Influent BOD and suspended solids concentrations have remained fairly constant over the last ten years averaging 173 and 229 mg/l respectively. The average daily flow is approximately 50 MGD and is increasing at an average of one percent per year.

The treatment plant includes grit removal, pre-aeration, primary settling with separate sludge digestion and disposal, trickling filters, final settling, and effluent chlorination.

The two grit basins are 40 ft. by 40 ft. by 3½ ft. deep. Approximately 15 cubic yards of grit are removed per day.

There are four pre-aeration basins 120 ft. long by 30 ft. wide by 16 ft. deep, designed to provide a detention time of 50 minutes at 50 MGD. This process is used as conditioning ahead of primary settling and air is normally introduced at a rate of approximately one cubic foot per cubic foot of wastewater.

There are three sedimentation basins each 80 ft. wide by 240 ft. long by 14 ft. deep, designed for a flow of 100 MGD. Approximately three tons of grease are skimmed from the tanks every day and 14,000 cubic feet of sludge containing 8½% to

10⅕% total solids are pumped to the digesters.

The twenty trickling filters each have a surface area of one-half acre and are 7½ feet deep. The filters are currently being renovated from one-pass standard rate filters to high-rate filters with recirculation. Six existing final 80 ft. diameter clarifiers are being supplemented by four 120 ft. diameter clarifiers. Humus sludge is returned to the primary plant ahead of grit removal. Improvements presently under construction will bring the total treatment plant capacity up to 100 MGD.

Sludge disposal is by anaerobic digestion. Digested sludge is pumped to lagoons where it is settled and the supernatant is pumped to adjacent fields.

Demonstration Project Plant

All facilities programmed to date still will not provide plant effluent characteristics needed to meet the water quality standards set for the Miami River. The City of Dayton recognized this fact and in 1965 decided to undertake a research and development study to investigate means of accomplishing higher levels of treatment. A part of this program was to study the use of conventional water treatment methods as a means of accomplishing tertiary wastewater treatment. In May 1966 a demonstration project grant was received from the Federal Water Pollution Control Administration to partially finance a demonstration project

entitled "Tertiary Treatment by Flocculation and Rapid-Sand Filtration."

The demonstration plant consists of an experimental trickling filter, pump and six inch main from the trickling filter, rapid-mix, flocculation and sedimentation basin, two rapid-sand filters, and chemical feed equipment.

In 1965 one standard rate trickling filter was renovated to study the effectiveness of direct recirculation without intermediate settling and with limited ventilation. Pumps were installed to provide a loading of 4.1 MGD primary effluent and 4.1 MGD recirculated filter effluent. This provided a loading of 20 to 25 pounds BOD per day per 1000 cubic feet of filter media, similar to the loading rate that will be imposed on the trickling filters currently being renovated for high-rate operation.

Effluent from the high rate filter is the source of water for the demonstration plant because this wastewater most closely approximates the overall plant effluent to be expected after secondary plant renovation is complete.

The flow from the high rate filter enters the rapid-mix unit (Figure 1) which consists of a tank 4 ft. in diameter by 4½ ft. deep and a five horsepower mixer. Detention time is 1.3 minutes at 310 gpm.

The flocculation basin is 16 ft. long by 10 ft. wide by

10 ft. deep and has a detention time of 39 minutes at 310 gpm. Flocculator tip speed is held at one fps for all tests except with lime. Lime floc settles in the flocculator basin at flocculator tip speed of one fps and requires slightly higher flocculator speeds to keep it suspended.

The sedimentation basin is 44 feet long by 10 feet wide by 10 feet deep and has a volume of 4400 cubic feet. The detention time is 105 minutes and the surface overflow rate is 1014 gpd/sf at 310 gpm. There are 100 lineal feet of effluent weirs with an overflow rate of 4464 gpd/lf at 310 gpm. The sludge collector system is a typical straight line collector.

Effluent from the settling tank is pumped through a flow meter to a flow splitter box. The meter is used to measure flow through the settling tank and to the rapid gravity filters.

The two filters (Figure 2) are set up to run in parallel or separately. The filters are seven feet in diameter and can be operated at heads of up to six feet above the static level of the equipment. The filters were manufactured by the Graver Water Conditioning Company to the city's specifications. The underdrains are a system of plastic strainers with conical protective hoods marketed as the "Roto-Scour Strainer" by Graver. The strainers were fastened to the false bottom of the filter and the media placed directly on them. The medium for one filter was 30 inches of AWWA B100 standard water filter

sand and media for the second filter included 10 inches of sand on the bottom and 20 inches of anthracite on top. The sand has an effective particle diameter of 0.40 to 0.45 mm with a uniformity coefficient of 1.35 to 1.70 and the anthracite has an effective particle size of 0.85 to 1.20 mm with a uniformity coefficient of 1.35 to 1.80.

The filters are designed for operation up to 310 gpm, that is, eight gpm/sf. The filtrate drain is elevated 2½ feet above the top of the media to control the water level in the filters. The operation of the filters departs from normal operation of water treatment filters in that the depth of water, thus the head, on the sand is not constant. Filters are operated at a constant influent flow rate and the depth of water above the sand increases with increasing friction loss through the sand. All record runs are terminated at 72 inches of head. Backwashing the filters is accomplished with an air scour, then back-flushing with filtrate.

The flocculation and settling basin units were placed in service in 1967 and the construction of the rapid-sand filters was completed in early 1968. Operation of the demonstration project began on March 29, 1968, and was terminated April 30, 1969, the end of the grant period.

The work in 1968 included the initial shakedown period where the tertiary treatment equipment was phased into service

and basic operational techniques were developed and several months of operation using alum coagulant with various flocculant aids. The operation was temporarily shut down in mid-December and resumed in early February 1969. The shut down period was used to effect some physical changes in the plant and was used as a period to bring the record keeping and analytical work up to date. The operation from February through April centered around work with lime and various flocculant aids. The priority for choice of chemicals used to this date has been based on their traditional roles in water treatment and laboratory bench scale work in this plant. Alum and lime were chosen as the primary coagulants and activated silica, Dow A-21, and ferric sulfate were chosen as the aids or secondary flocculants. Although other chemicals appear to merit consideration in this study, the number used to date has been deliberately limited because of available time to program their use.

Data were grouped into six major categories based on choice of coagulant, flocculant aid, and flow rate. The categories included:

1. Alum - 86 to 131 mg/l
   Activated silica - 9½% of alum dosage
   Wastewater flow - 200 to 225 gpm
   Settling basin surface overflow - 665 to 830 gpd/sf
   Detention time - 162 to 129 minutes
   Operation - September, October, and November 1968
   Number of observations - 27

2. Alum - 0 to 91 mg/l
   Activated silica - 9½% of alum dosage
   Wastewater flow - 290 to 315 gpm
   Settling basin surface overflow - 950 to 1035 gpd/sf
   Detention time - 115 to 105 minutes
   Operation - May, June, July, and August 1968
   Number of observations - 11

3. Alum - 30 to 90 mg/l
   Dow A-21 - 1.0 mg/l
   Wastewater flow - 270 to 315 gpm
   Settling basin overflow - 885 to 1035 gpd/sf
   Detention time - 122 to 105 minutes
   Operation - May, June, August, October, November 1968, and March 1969
   Number of observations - 33

4. Lime - 75 to 270 mg/l as CaO
   Dow A-21 - 1.0 mg/l
   Wastewater flow - 290 to 310 gpm
   Settling basin surface overflow - 980 gpd/sf average
   Detention time - 110 minutes average
   Operation - March 1969
   Number of observations - 15

5. Lime - 65 to 275 mg/l as CaO
   Activated silica - 2 mg/l as SiO_2
   Wastewater flow - 290 to 310 gpm
   Settling basin surface overflow - 980 gpd/sf average
   Detention time - 110 minutes average
   Operation - April 1969
   Number of observations - 7

6. Lime - 70 to 245 mg/l as CaO
   Ferric sulfate - 20 mg/l
   Wastewater flow - 200 gpm
   Settling basin surface overflow - 655 gpd/sf average
   Detention time - 165 minutes average
   Operation - April 1969
   Number of observations - 5

The number of observations is basically the number of days on which the chemical combination was tested. Test conditions were held constant throughout each day, i.e., alum feed rate, lime pH, and flocculant aid feed rate. During the alum tests

it was possible to operate only 8 to 16 hours per day, generally starting at 7:00 a.m. Thus, on a number of occasions it was necessary to shutdown the filters in mid-run and continue operation on the following day. In this event, chemical feed rates were held constant to completion of the filter run. Generally, each observation included at least one complete dual media filter run and several sand filter runs.

Lime tests were made on a 24 hour per day basis, testing each pH level over a one or two day period. Thus, data includes the results of several dual media filter runs and a number of sand filter runs.

Wastewater influent, settled effluent, and filter effluent samples were automatically collected on 15 minute intervals. During alum tests the samples were composited once a day for laboratory analysis and during the lime tests the samples were composited three times per day for analysis. All analyses were reported as a daily average.

EFFECTIVENESS OF CHEMICAL TREATMENT IN SETTLING

Analysis of Settling Tank Data

Data was graphically analyzed in order to correlate influent waste strength and chemical dosages with effluent waste strength and to facilitate data presentation. The number of variables in the treatment system are considerable and each variable complicated the task of isolating the meaningful relationships. Although much of the data is of limited value because of the nature of these variables, it has been graphed for presentation in this report.

The following graphs were made and are included in the appendix of this report:

1. Influent and effluent BOD, suspended solids, and phosphate in mg/l vs. coagulant dosage in mg/l.
2. Percent reduction of BOD and suspended solids vs. coagulant dosage in mg/l divided by influent loading of pollutant in mg/l.
3. Influent loading of BOD and suspended solids in mg/l vs. coagulant dosage in mg/l, noting percentage removals of BOD and suspended solids, and drawing a family of curves based on removals of BOD and suspended solids.
4. Pounds of phosphate removed per pounds of coagulant added vs. phosphate residual in effluent.

BOD Removals

General Results:

This series of tests indicates that BOD removal in secondary settling can be enhanced by the use of lime or alum and appropriate flocculant aids. However, they do not function nearly as well when the biological treatment process is not operating at its optimum. With a poor trickling filter effluent (due to season and periodic shutdown), settled effluents carrying approximately 20 mg/l BOD could be produced (88% overall removal), compared to a residual 46 mg/l BOD without chemicals (73% overall removal). The alum with activated silica tests point to the possibility that an effluent carrying 5 mg/l BOD (97% overall removal) may be produced in settling with chemical treatment under optimum conditions. Lime at pH 9.5 (150 mg/l CaO) and above consistently produced an effluent BOD of 25 mg/l (86% overall removal) or less with a relatively poor quality influent.

It appears that the trickling filter conversion of soluble BOD to insoluble BOD is important to chemical removal of BOD. Therefore, any project for the enhancement of the wastewater discharges should give consideration to improvement and protection of the biological treatment system.

Discussion:

Tests with alum and flocculant aids indicate that in low

alum dosage ranges, below 50 mg/l, the effluent quality tends to vary with quality of the influent (Figure 5). Above 60 mg/l of alum (with activated silica), effluent BOD level can be reduced and held near 5 mg/l when treating good secondary plant effluent.

The poor effluent quality (average 20 mg/l BOD) found with the use of alum and Dow A-21 (Figure 7) may be explained by the seasonal variation of the high-rate trickling filter effluent during that period. Data for alum feed rates up through 31 mg/l was gathered in October and November, 1968, while the filter was operating relatively well. In April and May, 1968, when the remainder of the data was gathered, filter effluent BOD was high and indications were that soluble BOD was not effectively being converted into insoluble BOD.

Investigation of high alum feed rates (90 to 130 mg/l) (Figure 6) indicated a decreasing percent of BOD removal with increases of alum. However, silica feeding during the period in which this data was gathered could not be maintained at the optimum of 9½% but was held at approximately the same rate throughout this set of runs, measuring less than 5% of the alum feed rate at the high alum dosage. Thus, results from this series of tests are of questionable reliability.

In order to eliminate some variable conditions in the data, BOD reduction was plotted as a function of the ratio of alum

feed rate to influent BOD - Figures 8, 9, and 10 indicate that there is a relationship between the ratio of alum dosage to influent BOD and the percent BOD reduction. Data correlation is not good, however, and the trend will require further confirmation. Considering the three graphs together, it appears that there may be predictable alum to influent BOD ratios for most efficient settling. There appears to be a correlation between the BOD reduction and the ratio of alum feed and BOD influent. The reason for scattering of data gathered to date may be due to the hourly and daily variations of sewage quality that occur, and seasonal variations in the quality of treatment.

Plotting of alum dosage versus influent BOD and noting the percent BOD reduction reveals the possibility of constructing a family of curves that may allow prediction of BOD removal levels based on any given alum dosage and knowledge of influent BOD (Figure 11). Of course, this knowledge can be useful in full scale operation only if a rapid approximation of BOD can be made. The testing involving alum and Dow A-21 is the only test series to date that reveals this relationship. More work must be done to confirm this relationship.

As yet, data are insufficient to compare the effectiveness of the two flocculant aids. Percentage removals of BOD are comparable at alum feeds below 30 mg/l. The decreasing percentage removal in Figure 9 might be at least partially

attributable to activated silica dosages falling below optimum. Experience with alum in jar tests and in the settling basin demonstrated that the alum with no flocculant aid formed a light, pinpoint floc that tended to be carried out of the basin. The addition of proper amounts of flocculant aid developed larger floc and enhanced settling.

Evaluation of BOD removal with lime treatment was performed during March and April, 1969. During this period the secondary plant was performing poorly due to interruptions caused by major plant construction work. The longest shutdown, three days, severely hindered the biological functioning of the filters. Effluent from the high-rate trickling filter to the demonstration plant was high in total and soluble BOD load.

During all tests, lime sludge was recirculated back to the flocculation basins at a rate of 50 gpm in order to simulate a sludge blanket. The density of the blanket was apparent in that most of the suspended matter was observed to settle out within the first five lineal feet of the settling tank.

It is felt that sludge recirculation may have two benefits:

1. Increased utilization of unspent lime and floc build-up, and,
2. Densification of sludge.

However, this remains to be proven.

Sludge was dewatered on open drying beds. Although relatively dense sludge was produced, further thickening prior to disposal may be of value in a full scale plant.

Analysis of lime removal with the various flocculant aids was complicated by the variations in quality of the wastewater sent to the demonstration project. Quite possibly lime with Dow A-21 (Figure 12) would have performed as well as or better than lime with activated silica (Figure 13), had conditions remained the same during both tests. Lime and activated silica produced a settled effluent containing 15 mg/l BOD or less (91% overall removal) at a pH above 9.5. Lime and ferric sulfate at the feed rates tested did not compare favorably with the other coagulant combinations with regard to final quality. The effluent quality unpredictably varied with influent quality at the higher dosage rates.

The lime and ferric sulfate (Figure 14) did not behave in a manner similar to the lime runs with A-21 and activated silica. At surface overflow rates approaching 1000 gpd/sf and with sludge recirculation there was heavy floc carryover at the effluent weirs. A settling tank flow rate of 200 gpm (650 gpd/sf) was found to be the maximum at which good settling was achieved with lime and ferric sulfate. A one-day run, however, at 300 gpm without sludge recirculation yielded a high quality effluent, indicating that further study of sedimentation should be pursued.

Analysis of BOD reduction in settling as a function of the ratio of CaO applied to influent BOD yielded patterns similar to those found with alum treatment. A-21 in combination with lime (Figure 15) indicated increased efficiency by increasing the lime to influent BOD ratios, as indicated by the upward sloping line. However, the reason for this effect is not understood and may well lie in the nature of the flocculant aid or in the fact that influent BOD (and suspended solids) was continually rising during the test series.

Conditions during the lime and activated silica tests were more ideal. BOD loadings did not vary significantly during the test series. The analysis of BOD reduction as a function of the ratio of CaO applied to BOD influent (Figure 16) gave good correlation, indicating that under those test conditions, a chemical dosage can be selected to yield a given effluent on a BOD basis. These relationships were found despite poor influent characteristics. It would appear that these relationships would be enhanced with better quality influent.

Testing of lime and ferric sulfate was very limited, and the plotting of BOD reduction as a function of CaO applied to BOD influent (Figure 17) is felt to be of little significance. The graph is included simply for comparison.

Suspended Solids Removal

General Results:

In the series of tests with alum and lime as primary coagulants it was possible to produce an effluent carrying 25 mg/l suspended solids or less (89% overall removal). Twenty mg/l suspended solids residual (91% overall removal) was reached but could not be maintained during all tests. Twenty-five mg/l of suspended solids appears to be the best effluent, consistently producable with lime or alum. Tests with flocculation and settling but without chemicals produced an effluent with a residual of 35 mg/l suspended solids (85% overall removal).

A high degree of chemical treatment in secondary settling does not appear to offer a method for a high degree of solids removal and probably could not be justified on the basis of suspended solids removal alone. Comparison of suspended solids removal data with BOD removals indicates two possibilities; a portion of the suspended matter is coagulant chemical being carried out of the basin, or a portion of the soluble BOD is being chemically precipitated and settled out.

Discussion:

Extensive laboratory study of settled trickling filter effluent has indicated and demonstration work has confirmed that a high percentage of the BOD is associated with the suspended solids. Furthermore, the suspended matter in the wastewater may settle in the receiving stream to form objectionable sludge deposits or may rise under certain conditions to form an

objectionable film or scum. Thus, the reduction of suspended solids is important if water quality objectives are to be met.

Graphical interpretation of suspended solids data indicates that precipitation of suspended solids with alum and activated silica varies in a pattern similar to the influent suspended solids (Figure 19). In contrast, the alum and A-21 treatment yielded an effluent of uniform quality, despite fluctuations in the influent quality (Figure 21). Fluctuations in quality of the influent during the alum and A-21 tests can be attributed to parts of the work being performed during different seasons as discussed previously. It is important to note, however, that throughout the range of the tests, up to 90 mg/l of alum, the quality of the effluent steadily improved. The alum and activated silica developed a uniform effluent at some point above 60 mg/l of alum (Figure 20).

Graphical comparison of percent suspended solids reduction with the ratio of alum dosage to influent suspended solids indicates some significant differences in settling characteristics between the two flocculant aids. With activated silica (Figures 22 and 23) the optimum alum to suspended solids ratio is less than 1.0. In contrast, the alum and Dow A-21 tests (Figure 24) had not yet reached a peak for suspended solids removal at an alum to influent suspended solids ratio greater than 2.0. If this relationship is verified in future testing, its significance

will lie in the fact that there is an alum and activated silica level beyond which settling is inhibited, thus limiting the degree of treatment possible in settling.

It should again be pointed out that due to difficulties in control of the activated silica feed, the results of these tests in the range of 200 to 255 gpm are subject to improvement under more optimum conditions. At the higher alum feed rate and high alum to suspended solids influent ratios the activated silica was below optimum levels, based on jar tests.

Plotting influent suspended solids in mg/l versus alum dosage in mg/l, notation of percentage removals (Figure 25) indicates that the A-21 tests may yield a family of curves relating alum and influent loading to suspended solids removals. Although of limited value because of the small number of tests, these curves have been projected. The two sets of tests involving use of alum and activated silica did not lend themselves to presentation in this manner and further testing will be required to demonstrate such a relationship.

During evaluation of suspended solids removals with lime and A-21 (Figure 26), the suspended solids in the influent wastewater steadily increased, making difficult the evaluation of this series of tests. The inability to produce an effluent containing less than 30 mg/l of suspended solids may be due to a change in the nature of the wastewater coming into the primary

and secondary plant, or may be related to changes in the biological activity in the trickling filter.

Evaluation of lime and activated silica (Figure 27) under more ideal conditions indicates that an effluent suspended solids concentration of 20 mg/l can be achieved by sedimentation with lime doses in the vicinity of 250 mg/l and above. From the graphs for both lime with activated silica and lime with A-21 it appears that lime doses above the range of 120 to 150 mg/l (pH 9.5) will produce an effluent that is relatively uneffected by sharp changes in influent wastewater quality. Under the much poorer test conditions encountered with the use of A-21 in conjunction with the lime, the effluent produced was comparable to that produced with activated silica under better conditions. Again, the indication is that the lime and A-21 may work as well as or better than lime and activated silica under the same test conditions.

The lime and ferric sulfate behaved poorly and unpredictably in removing suspended solids, as similarly noted in the discussion of BOD removals. The flow through the settling tank was reduced by 1/3 in order to gain reasonable settling of the floc. One run without sludge recirculation developed a considerably higher quality effluent in settling at the regular flow rate of 300 gpm. The need for work in the area of lime and ferric sulfate treatment without recirculation is

indicated.

Suspended solids removals plotted as a function of the ratio of CaO applied to influent suspended solids for A-21 flocculant aid (Figure 29) yields a good grouping of data points. However, the spread of data relating the CaO to influent suspended solids is small and more data is needed before conclusions can be drawn.

Analysis of suspended solids reductions indicate that 70% reduction can be anticipated in final settling at 3-3/4 parts of CaO per part of influent suspended solids (Figure 30), with activated silica flocculant aid. However, correlation is poor and indicates the need for further work.

Figure 31, suspended solids reductions as a function of CaO applied to influent suspended solids with ferric sulfate, is presented for comparison. More work must be done before conclusions can be drawn regarding lime and ferric sulfate.

Figure 18 is a family of curves depicting the suspended solids reductions that might be anticipated at various influent suspended solids loadings and lime feed rates, using A-21 as a flocculant aid. Although these curves represent a very liberal interpretation of the available data, it is felt that under better conditions (more uniform secondary plant operations), data will support such curves. Testing with activated silica and ferric sulfate was not sufficient to develop this type of chart.

Phosphate Removal

General Results:

Work without chemicals indicates that most of the phosphate received in the primary plant is in a soluble form and that very little is insolublized and removed in primary or secondary treatment, or in sand filtration. Thus, chemicals are necessary to precipitate the phosphate so it can be removed in settling and sand filtration.

Alum used in settling can be relied upon to remove at least 0.2 pounds of phosphate per pound of alum applied, up to a residual of 4 mg/l phosphate. Alum with activated silica performed somewhat better than alum with the organic polyelectrolyte. Phosphate removal up to a residual of 4 mg/l with alum (89% overall removal) is a constant or slightly decreasing ratio with increasing removals, beyond which the alum requirement for phosphate removal rises sharply. It appears that over 200 mg/l of alum would be necessary to reduce phosphate residuals to the range of 1 to 2 mg/l.

Phosphate removal with lime in settling appears promising. Using lime and activated silica it was possible to develop an effluent residual of 4 mg/l phosphate (89% overall removal) at a pH 9.5, approximately 160 mg/l CaO. It may be possible to consistently achieve phosphate residuals of 2 mg/l (94% overall removal) or even 1 mg/l (97% overall removal) at pH 11+.

Removal was less effective with lime and the organic polyelectrolyte.

Discussion:

The phosphate ion, PO_4^{---}, has an atomic weight of 95. Commercial aluminum sulfate, generally sold as $Al_2 (SO_4)_3 \cdot 14 H_2O$, has an atomic weight of 594. Precipitation of phosphate with aluminum on a one-to-one ionic basis will yield 0.32 pound phosphate per pound of alum as a theoretical maximum. Lime, as CaO, has an atomic weight of 56. Assuming the lime to be 100% available CaO, one pound of lime will precipitate 1.14 pounds of phosphate as a theoretical maximum. In reality, the lime precipitates much less phosphate.

All graphs of phosphate removal with alum and lime demonstrate that phosphate removal is a function of coagulant dosage. The chart showing phosphate removal with alum and activated silica (Figure 32) is the most outstanding. Figure 33 is essentially an extension of Figure 32 showing increased removals at higher alum dosages.

Alum and A-21 (Figure 34) produced an effluent comparable in phosphate residuals to alum and activated silica.

In order to more closely examine phosphate removal, graphs were made of phosphate residual versus the ratio of phosphate removed to coagulant dosage. Analysis of alum and activated silica data for lower alum dosages (Figure 38) revealed that

phosphate removal to alum dosage ratios ranged from 0.18 to 0.35 and averaged 0.26. In the higher range of alum feed rates (Figure 39), the range of removals was 0.17 to 0.23 with an average 0.20.

Phosphate removal to alum dosage ratios with alum and A-21 ranged from 0.10 to 0.43 and averaged 0.20. Comparing alum and A-21 to alum and activated silica in the two alum dosage ranges indicates that the alum and activated silica provided slightly better phosphate removals than alum and Dow A-21.

Lime was fed on the basis of pH, starting at 9.0. Thus, no work was done with lime doses below approximately 70 mg/l CaO. It was later found that this left a considerable gap in phosphate removal data. On an overall basis in the chemical feed range of 75 to 90 mg/l, lime appears to be at least comparable to alum for phosphate removal on a pound-per-pound coagulant basis. Lime with one mg/l A-21 (Figure 35) and lime with two mg/l activated silica (Figure 36) produced consistent phosphate removals throughout the lime doses tested. Lime and ferric sulfate (Figure 37) produced an effluent of fluctuating quality over the range of lime dosages tested.

Examination of pounds of phosphate removed per pounds of CaO applied indicate that lime and A-21 (Figure 41) provide slightly better removals at the lower lime dosage than lime and activated silica (Figure 42) and that lime and activated

silica performs slightly better at the higher lime feed rates. However, data is insufficient to draw firm conclusions at this time regarding the merits of A-21 and activated silica used in conjunction with either lime or alum.

Figure 43, concerning the use of lime and ferric sulfate, is inconclusive and is included only for comparison.

EFFECTIVENESS OF RAPID-SAND FILTRATION

General Results

It has been demonstrated that rapid-sand filtration can effectively be used to polish plain settled or chemically treated and settled trickling filter effluents. Filtration following plain sedimentation can produce a suspended effluent of 18 mg/l (92% overall reduction) and a BOD effluent of 35 mg/l (80% overall reduction) at filter loading rates of 4 gpm/sf when the trickling filters are operating poorly. Higher removals were experienced during periods of good secondary treatment. With chemical treatment in settling it was possible to polish effluents to a degree not attainable in settling alone. The filters also provided additional removal of chemically precipitated phosphate, generally capturing 30% to 70% of the phosphate imposed on it.

The dual media filter using 20 inches of anthracite and 10 inches of sand produced an effluent comparable in quality to the sand filter using 30 inches of sand with filter runs up to two to three times the length of the sand filter runs.

Graphical analysis of data did not reveal any relationships between suspended solids influent and effluent strength, percent solids removals, pounds of solids removed per run, and chemical dosage in settling.

Discussion

Rapid-sand filtration is a process of using sand to strain from a liquid stream the particulate matter. It is a mechanical process and the removal of other materials such as phosphate and BOD will be a secondary result due to the association of those materials with the particulate matter. It is the function of chemical treatment to precipitate and flocculate into large particles those materials that might otherwise pass through the filter.

In order to more closely define filterability, the following possible relationships were investigated:

1. Volume of filtrate vs. pounds of suspended solids removed.
2. Length of filter run vs. pounds of suspended solids removed.
3. Length of filter run vs. pounds of influent suspended solids.
4. Influent suspended solids load vs. effluent suspended solids load at various chemical dosages in settling.
5. Chemical dosage in settling vs. pounds of suspended solids removed on filters.
6. Chemical dosage in settling vs. percent suspended solids removed.

7. Volume of filtrate vs. chemical dosage in settling.

8. Length of filter run vs. chemical dosage in settling.

In no case did a clear pattern evolve. Therefore, data were grouped and averaged as shown on the following pages and plotted on graphs with settling tank data. In almost every case the data shown represents several filter runs that vary widely in length of filter run, influent and effluent quality, and removals.

The data should not be interpreted at this time as the effluent qualities that can be expected in filtration with the given levels of chemical treatment. Running concurrently with the settling tests, each series of filtration tests (e.g. lime with A-21, alum with activated silica) took place during a period of several weeks. Annual variations in raw wastewater quality and trickling filter effluent may cause significant chemical treatment characteristics not observed to date.

Dual Media Filter:

The filtration experiments point to the value of dual media filtration. Longer filter runs were experienced with the anthracite-sand combination than with plain sand. Furthermore, as the filtration rates was increased, the dual media filter showed a more marked advantage over the sand filter. Comparison of alum and activated silica data shows that at

loading rates below 3.4 gpm/sf the ratio of dual media filter to sand filter filtrate volume is 1.82; at loading rates of 4 gpm/sf the ratio is 2.51.

This effect may partially be due to the reduction in sand depth and subsequent reduction in friction loss through sand, as well as interception of the large floc particles in the anthracite resulting in reduction of friction loss at the "schmutzdecke" at the sand-anthracite interface. Actual friction losses through the filters have not been measured. Friction loss measurements will be made in the future.

Alum Treatment:

The most extensive testing to date involves use of alum, assisted in settling by flocculant aids. The filters were loaded at rates generally falling into the following categories:

2.6 to 3.4 gpm/sf

3.4 to 5.0 gpm/sf

5.0 to 7.0 gpm/sf

Most of the demonstration work was performed in the range of 3.8 to 4.1 gpm/sf.

Comparison of filtration data using alum with the two flocculant aids in settling indicates that the Dow A-21 produced approximately 25% longer filter runs than the activated silica. The alum with A-21 and the alum with activated silica both

produced filtrate comparable in quality on a suspended solids, BOD, and phosphate basis. It was also observed that the volume per filter run tended to increase as chemical treatment increased. Of importance also is the fact that effluent quality was not significantly effected by changing filter loading rates.

Alum treatment exerts no disinfection on the wastewater stream and thus the sand filters periodically developed an algae growth that inhibited filtration. It was found that chlorinating the wastewater stream just ahead of the filters so that a trace residual remained in filter effluent had the effect of keeping the filters clean as well as disinfecting the final effluent. Chlorine was applied to rates between 3.5 and 5.0 mg/l.

Lime Treatment:

Lime treatment utilized control by pH as is done in water softening. Data correlating feed rates to removals is being accumulated to verify the usefulness of this method of control. The pH of the wastewater stream was controlled at the rapid mix and was found in the higher pH level to drop 0.3 to 0.4 units with retention in the settling basin, probably due to precipitation of carbon dioxide introduced from the air above the settling tank. Thus, filter influent (settling tank effluent) had a slightly lower pH than that reported.

The high pH associated with high lime doses had the

advantage of controlling slime growth on filters. There was no visible slime growth on the sand during filtration of lime treated wastewater. Periodic or continual chlorination of filter influent was not required.

Sand growth was experienced with the use of lime, particularly when the activated silica was used as a flocculant aid. The sand bed expanded almost two inches in one week. Microscopic examination of sand grains revealed little. However, it was found that heating the sand at 103° C for several minutes caused the chemical growth to slough. The need for further work is indicated toward stabilizing by recarbonation with CO_2 gas before entering the filter.

Data trends indicate that lime with activated silica flocculant aid produced a settled wastewater that gave substantially longer filter runs than lime with either the Dow A-21 or the ferric sulfate. This might be partially attributable to sand growth. However, removal of suspended solids, BOD, and phosphate on the filter was higher and more consistent than with the A-21 or ferric sulfate.

RAPID SAND FILTER PRODUCTION
Alum and Activated Silica
(at 9½% of Alum Feed Rate) Flocculant Aid *

	SAND FILTER								
Alum Dosage - mg/l	0	30 to 39	40 to 49	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119	130 to 139
Filter Loading <3.4 gpm/sf										
Gallons per square foot per run		395		885	890	1015	1010		1260	1440
% Suspended Solids Removed		40		63	45	44	60		74	55
lb. Suspended Solids Removed/sf/run		.067		.148	.101	.073	.093		.093	.041
Avg. Suspended Solids in Effluent, mg/l		31		15	17	8	7		12	3
Avg. Filter Loading gpm/sf		3.14		3.38	3.20	2.75	2.83		2.93	2.81
BOD Removed, %		70		-	83	34	28		28	30
BOD in Effluent, mg/l		6		-	3	6	5		6	8
PO_4 Removed, %		35		16	35	29	32		56	31
PO_4 in Effluent, mg/l		16.8		15.4	6.4	5.5	3.9		2.2	3.2
Filter Loading - 3.4 to 5.0 gpm/sf										
Gallons per square foot per run	1680	315	400	705		755		865	1010	
% Suspended Solids Removed	59	50	39	55		62		51	77	
lb. Suspended Solids Removed/sf/run	.067	.065	.062	.101		.122		.075	.143	
Avg. S.S. in Effluent, mg/l	19	24	30	14		12		10	5	
Avg. Filter Loading, gpm/sf	3.80	3.95	4.03	3.85		4.05		4.00	4.13	
BOD Removed, %	45	63	69	10		9		46	24	
BOD in Effluent, mg/l	9	8	5	4		5		3	9	
PO_4 Removed, %	1	20	21	25		29		29	40	
PO_4 in Effluent, mg/l	28.0	22.5	16.2	12.7		5.5		5.5	2.6	
Filter Loading >5.0 gpm/sf										
Gallons per square foot per run						675	850			
% Suspended Solids Removed						56	70			
lb. Suspended Solids Removed/sf/run						.091	.099			
Avg. S.S. in Effluent, mg/l						7	6			
Avg. Filter Loading, gpm/sf						5.00	5.00			
BOD Removed, %						0	0			
BOD in Effluent, mg/l						6	7			
PO4 Removed, %						25	59			
PO4 in Effluent, mg/l						5.0	1.5			

* Chemical additions shown were used to enhance settling prior to rapid-sand filtration.

RAPID SAND FILTER PRODUCTION
Alum and Activated Silica
(at 9½% of Alum Feed Rate) Flocculant Aid *

DUAL MEDIA FILTER

Alum Dosage - mg/l	0	30 to 39	40 to 49	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119	120 to 129
Filter Loading <3.4 gpm/sf										
Gallons per square foot per run					1900	2230	2100		1630	2960
% Suspended Solids Removed					43	66	68		63	87
lb. Suspended Solids Removed/sf/run					.202	.228	.319		.130	.117
Avg. S.S. in Effluent, mg/l					18	7	11		6	1
Avg. Filter Loading, gpm/sf					3.11	2.78	3.01		3.07	2.84
BOD Removed, %					97	32	18		35	50
BOD in Effluent, mg/l					1	6	6		7	5
PO_4 Removed, %					38	35	40		35	17
PO_4 in Effluent, mg/l					6.5	4.4	4.9		3.0	3.5
Filter Loading - 3.4 to 5.0 gpm/sf										
Gallons per square foot per run	3050	1030	1155	1690		1570	1820	1830	2380	1300
% Suspended Solids Removed	59	47	59	50		55	68	55	69	65
lb. Suspended Solids Removed/sf/run	.262	.197	.278	.195		.244	.093	.127	.218	.260
Avg. S.S. in Effluent, mg/l	21	26	20	14		15	4	6	5	13
Avg. Filter Loading, gpm/sf	3.90	3.97	3.43	3.82		4.05	3.71	4.00	4.62	3.97
BOD Removed, %	45	61	56	45		35	33	30	69	13
BOD in Effluent, mg/l	9	8	7	2		3	6	6	5	5
PO_4 Removed, %	1	25	34	29		21	28	30	47	47
PO_4 in Effluent, mg/l	28.0	20.6	13.4	12.0		13.0	5.4	5.7	1.6	4.8
Filter Loading >5.0 gpm/sf										
Gallons per square foot per run				1180		520	1060	1955		2610
% Suspended Solids Removed				46		76	96	82		90
lb. Suspended Solids Removed/sf/run				.119		.039	.257	.434		.935
Avg. S.S. in Effluent, mg/l				14		12	2	6		4
Avg. Filter Loading, gpm/sf				5.00		6.97	5.98	5.30		5.06
BOD Removed, %				100		23	67	70		23
BOD in Effluent, mg/l				0		5	1	4		10
PO4 Removed, %				30		32	31	65		24
PO4 in Effluent, mg/l				11.4		5.6	6.7	1.8		1.9

* Chemical additions shown were used to enhance settling prior to rapid-sand filtration.

RAPID SAND FILTER PRODUCTION

Alum and Dow A-21 (at 1 mg/l) Flocculant Aid *

SAND FILTER

Alum Dosage - mg/l	10 to 19	20 to 29	40 to 49	50 to 59	60 to 69	80 to 89	90 to 99	100 to 109	110 to 119	190 to 200
Filter Loading 3.4 gpm/sf										
Gallons per square foot per run				1310	945	1250	1180	1620	1410	
% Suspended Solids Removed				78	69	40	60	70	86	
lb. Suspended Solids Removed/sf/run				.153	.093	.052	.083	.096	.070	
Avg. S.S. in Effluent, mg/l				4	5	6	6	3	1	
Avg. Filter Loading, gpm/sf				2.65	3.35	2.75	3.04	2.89	3.38	
BOD Removed, %				25	50	9	29	61	100	
BOD in Effluent, mg/l				3	4	10	4	3	0	
PO_4 Removed, %				44	32	47	24	55	22	
PO_4 in Effluent, mg/l				1.8	3.4	5.6	2.7	1.4	2.5	
Filter Loading - 3.4 to 5.0 gpm/sf										
Gallons per square foot per run	723	410	335					1330		590
% Suspended Solids Removed	40	51	57					56		85
lb. Suspended Solids Removed/sf/run	.101	.083	.078					.169		.096
Avg. S.S. in Effluent, mg/l	25	23	21					8		3
Avg. Filter Loading, gpm/sf	3.95	4.05	4.11					4.26		3.95
BOD Removed, %	24	78	66					30		40
BOD in Effluent, mg/l	10	4	4					6		10
PO_4 Removed, %	2	18	27					61		78
PO_4 in Effluent, mg/l	32.1	26.7	16.4					2.1		1.1

* Chemical additions shown were used to enhance settling prior to rapid sand filtration.

RAPID SAND FILTER PRODUCTION
Alum and Dow A-21 (at 1 mg/l) Flocculant Aid *

DUAL MEDIA FILTER

Alum Dosage - mg/l	0	10 to 19	20 to 29	40 to 49	60 to 69	80 to 89	100 to 109	120 to 129	130 to 139	190 to 200
Filter Loading < 3.4 gpm/sf										
Gallons per square foot per run					3310	2640		2230		
% Suspended Solids Removed					60	100		18		
lb. Suspended Solids Removed/sf/run					.249	.021		.075		
Avg. S.S. in Effluent, mg/l					4	0		18		
Avg. Filter Loading, gpm/sf					2.62	3.38		3.09		
BOD Removed, %					0	43		33		
BOD in Effluent, mg/l					6	8		8		
PO_4 Removed, %					40	37		45		
PO_4 in Effluent, mg/l					3.0	6.2		1.7		
Filter Loading - 3.4 to 5.0 gpm/sf										
Gallons per square foot per run	3050	2230	1520	1125			2600		3270	2040
% Suspended Solids Removed	59	36	46	54			53		39	77
lb. Suspended Solids Removed/sf/run	.262	.280	.252	.226			.174		.244	.306
Avg. S.S. in Effluent, mg/l	21	27	23	20			7		14	5
Avg. Filter Loading, gpm/sf	3.90	4.00	4.00	4.03			4.00		4.21	4.00
BOD Removed, %	45	25	72	45			60		82	43
BOD in Effluent, mg/l	9	6	5	7			2		2	10
PO_4 Removed, %	1	7	8	17			56			79
PO_4 in Effluent, mg/l	28.0	32.0	30.4	18.6			2.7			1.0
Filter Loading > 5.0 gpm/sf										
Gallons per square foot per run							2100			
% Suspended Solids Removed							62			
lb. Suspended Solids Removed/sf/run							.351			
Avg. S.S. in Effluent, mg/l							12			
Avg. Filter Loading, gpm/sf							6.36			
BOD Removed, %							95			
BOD in Effluent, mg/l							1			
PO4 Removed, %							28			
PO4 in Effluent, mg/l							5.5			

* Chemical additions shown were used to enhance settling prior to rapid sand filtration.

RAPID SAND FILTER PRODUCTION

Lime (measured as CaO) with Dow A-21 Flocculant Aid *

Sand Filter

pH	7.0	9.0	9.2	9.8	10.2	10.8	11.2
Gallons per square foot per run	475	490	480	690	1300	960	640
% Suspended Solids Removed	49	69	48	53	31	26	37
lb. Suspended Solids Removed/sf/run	.067	.049	.047	.067	.067	.073	.039
Avg. S.S. in Effluent, mg/l	18	10	18	9	15	20	12
Avg. Lime (as CaO) dosage, mg/l	-	64	80	127	162	215	275
Avg. Flocculant Aid dose, mg/l	-	1.0	1.0	1.1	1.1	1.3	1.8
BOD Removed, %	24	12	18	13	21	35	18
BOD in Effluent, mg/l	35	21	18	13	19	19	14
PO_4 Removed, %	1	42	43	52	35	34	40
PO_4 in Effluent, mg/l	28.0	5.1	5.4	4.2	3.9	3.3	1.8

Dual Media Filter

pH	7.0	9.0	9.2	9.8	10.2	10.8	11.2
Gallons per square foot per run	2240	1285	1205	2370	2380	2040	2440
% Suspended Solids Removed	40	63	40	42	9	35	39
lb. Suspended Solids Removed/sf/run	.262	.213	.138	.169	.080	.171	.112
Avg. S.S. in Effluent, mg/l	21	12	21	11	20	19	14
Avg. Lime (as CaO) dosage, mg/l	-	64	80	127	162	215	275
Avg. Flocculant Aid dose, mg/l	-	1.0	1.0	1.1	1.1	1.3	1.8
BOD Removed, %	24	29	18	7	29	36	21
BOD in Effluent, mg/l	35	17	18	14	17	18	15
PO_4 Removed, %	1	50	39	56	28	34	37
PO_4 in Effluent, mg/l	28.0	4.4	5.8	3.9	3.8	3.3	1.9

NOTE: All tests made at approximately 4.00 gpm/sf filter loading rate.

* Chemical additions shown were used to enhance settling prior to rapid sand filtration.

RAPID SAND FILTER PRODUCTION

Lime (measured as CaO) with Activated Silica *

Sand Filter

pH	7.0	9.0	9.2	9.5	10.0	10.5	11.0
Gallons per square foot per run	475	730	695	1310	1465	1670	1195
% Suspended Solids Removed	49	69	63	77	57	61	74
lb. Suspended Solids Removed/sf/run	.067	.158	.156	.218	.231	.153	.140
Avg. S.S. in Effluent, mg/l	18	11	16	6	14	7	5
Avg. Lime (as CaO) dosage, mg/l	-	76	94	165	190	239	265
Avg. Flocculant Aid dose, mg/l	-	2.2	1.7	2.3	1.8	2.1	1.9
BOD Removed, %	24	37	18	29	12	36	-
BOD in Effluent, mg/l	35	15	16	10	14	7	-
PO_4 Removed, %	1	50	50	7	48	57	50
PO_4 in Effluent, mg/l	28.0	5.3	4.2	1.3	3.0	1.3	0.3

Dual Media Filter

pH	7.0	9.0	9.2	9.5	10.0	10.5	11.0
Gallons per square foot per run	2240	1630	1410	3070	1735	2240	1655
% Suspended Solids Removed	40	57	58	43	31	50	74
lb. Suspended Solids Removed/sf/run	.262	.270	.293	.151	.073	.169	.054
Avg. S.S. in Effluent, mg/l	21	15	18	8	11	9	5
Avg. Lime (as CaO) dosage, mg/l	-	76	94	165	190	239	265
Avg. Flocculant Aid dose, mg/l	-	2.2	1.7	2.3	1.8	2.1	1.9
BOD Removed, %	24	50	36	73	55	36	-
BOD in Effluent, mg/l	35	12	14	7	15	7	-
PO_4 Removed, %	1	46	47	-	48	67	50
PO_4 in Effluent, mg/l	28.0	5.8	4.4	2.2	3.0	1.0	0.3

NOTE: All tests made at approximately 4.00 gpm/sf filter loading rate.

* Chemical additions shown were used to enhance settling prior to rapid sand filtration.

RAPID SAND FILTER PRODUCTION

Lime (measured as CaO) with Ferric Sulfate**

	SAND FILTER					DUAL MEDIA FILTER				
pH	7.0	9.0	9.4	9.5	9.5*	7.0	9.0	9.5	9.6	10.5
Gallons per square foot per run	475	500	810	865	825	2240	1520	4050	1970	3690
% Suspended Solids Removed	49	61	76	37	92	40	57	-	38	55
lb. Suspended Solids Removed/sf/run	.067	.088	.402	.062	.184	.262	.314	-	.395	.306
Avg. S.S. in Effluent, mg/l	18	17	19	15	2	21	19	24	39	8
Avg. Lime (as CaO) dosage, mg/l	-	72	131	138	141	-	72	138	182	241
Avg. Flocculant Aid dose, mg/l	-	24	21	20	21	-	24	20	21	20
BOD Removed, %	24	29	48	0	14	24	36	62	39	42
BOD in Effluent, mg/l	35	20	15	13	6	35	18	5	20	15
PO_4 Removed, %	1	37	68	64	48	1	48	71	30	68
PO_4 in Effluent, mg/l	28.0	5.8	4.2	0.9	2.6	28.0	4.8	0.8	6.3	1.1

* Sludge recirculation in settling tank not in operation.
Sludge recirculated during all other settling tank and filter runs.

NOTE: All tests made at approximately 4.00 gpm/sf filter loading rate.

** Chemical additions shown were used to enhance settling prior to rapid sand filtration.

BACKWASHING OF FILTERS

The physical design of the filters allowed for six foot headloss through the filters. When this maximum head was reached, the water in the unit was allowed to drain to a level approximately three inches above the sand surface. The manufacturer's instructions called for an air scour at the rate of five cfm/sf (192.5 cfm) for five minutes introducing water at 3-3/4 gpm/sf (145 gpm) during the last minute of air scour. When the air scour was shut off, the backwash rate was to be increased to 15 gpm/sf (577 gpm) for ten minutes. This procedure was modified as follows:

1. Five minutes of air scour at 250 cfm for increased scouring action.
2. Introduce backwash water at 145 gpm, shut off air, continue water flow at 145 gpm for three minutes to bleed air from plenum chamber.
3. Increase backwash rate to 577 gpm and operate for five minutes on sand filter (eight minutes on dual media filter), then allow 3/4 minute to close valve on backwash line.

It was found that several minutes were required to bleed the residual air from the plenum. Air bubbles during the 577 gpm backwash cycle tended to carry media into the backwash

trough, especially from the dual media filter. The length of the backwash cycle was chosen on the basis of visual observations, noting in all cases that during the earlier filter runs backwashing the sand filter for five minutes and the dual media for eight minutes carried out virtually all visible floc. Theoretically, this generates washwater volumes on the order of 92 gal./sf and 139 gal./sf for the sand filter and dual media filter respectively. Thus, washwater volume becomes a function of the length of filter run or the volume of water filtered.

In actual operation, backwash meter readings indicated that 85 gal./sf and 127 gal./sf were being used on the sand filter and dual media filter respectively. The backwash water was noted to contain several thousand mg/l of suspended solids and that the solids settled rapidly under quiscent conditions. No further work has been to date with regard to reprocessing backwash water.

The following two pages give data on backwash water as a percent of filtrate volume. Data corresponds to the previous pages entitled Rapid-Sand Filter Production. It is the conclusion of operating personnel that significant reduction in backwash water as a percent of filtrate will occur primarily as a function of increased filter production, not as a reduction of the backwash water required for each backwash cycle.

FILTER BACKWASH WATER AS A PERCENT OF FILTRATE

Alum Dosage - mg/l	0	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119	120 to 129	130 to 139	190 to 200
Alum + A-21															
Sand Filter	5.0	12.2	20.8		25.3						6.4				14.5
Dual Media Filter	4.2	5.7	8.4		11.3						4.9			3.9	6.2
Alum + Activated Silica															
Sand Filter	5.0			26.8	21.1		12.0		11.2		9.8	8.4			
Dual Media Filter	4.2			12.4	11.0		7.5		8.1	7.0	6.9	5.3	9.8		

Calculations based on filter runs with loading 3.4 to 5.0 gpm/sf.

Backwash based on 3270 gal. (85 gal./sf) for sand filter and 4890 gal. (127 gal./sf) for dual media filter.

FILTER BACKWASH WATER AS A PERCENT OF FILTRATE

pH	7.0	9.0	9.2	9.4	9.5	9.8	10.0	10.2	10.5	10.8	11.0	11.2
Lime + A-21												
Sand Filter	17.9	17.4	17.7			12.3		6.6		8.9		14.3
Dual Media Filter	5.7	10.1	10.5			5.4		5.3		6.2		5.2
Lime + Activated Silica												
Sand Filter	17.9	11.7	12.2		6.5		5.8		5.1		7.1	
Dual Media Filter	5.7	7.8	9.0		4.1		7.3		5.7		7.7	
Lime + Ferric Sulfate												
Sand Filter	17.9	17.0		10.5	9.8							
Dual Media Filter	5.7	8.4			4.2				3.4			

Calculations based on filter runs with loading approximately 4.0 gpm/sf.

Backwash based on 3270 gal. (85 gal./sf) for sand filter and 4890 gal. (127 gal./sf) for dual media filter.

SLUDGE DISPOSAL

Although it is today technically possible to satisfactorily treat virtually any wastewater, sludge disposal has become, in many cases, a problem almost equal in magnitude to the problem of wastewater treatment. Increasing sludge volumes, the foul and dangerous nature of the material, the advent of sludge from chemically treated wastewater, and the increasing cost and dwindling supply of open land for disposal are magnifying the problem. The traditional methods of open land and pit disposal are less and less acceptable. The alternatives to open land or pit disposal are expensive and all are not suited to every application.

In planning for the demonstration project the sludge disposal problem was recognized but a complete analysis of sludge disposal was felt to be beyond the scope of the project. Facilities were provided to measure sludge withdrawals and samples were periodically analyzed for total solids. However, data to date is not conclusive. Provision will be made in the future for greater control of sludge removal, with density and total solids analysis of sludge.

It is proposed that future work with the project will include provision for bench scale tests to study the feasibility of mechanical dewatering characteristics, incineration of dewatered sludge, and recalcination of lime sludge.

EFFLUENT DISINFECTION

Disinfection of treated wastewater effluent has become a popular method of destroying residual pathogenic bacteria that remain in wastewater treatment plant effluents and might otherwise be discharged to a watercourse. The technique usually involves chlorination and detention of plant effluent prior to discharge. Other methods are available, including use of ozone and pH adjustment. There are many unanswered questions concerning the use of chlorine including the effect of residual chlorine on aquatic life and formation of chlorinated organic compounds in the wastewater.

In operation of the demonstration project using alum and a coagulant aid, it was found that an algae growth formed on the sand filters. This was controlled by treating the filter influent with chlorine at a point just downstream from the filter feed pump. Turbulence in the line and flow splitter box provided mixing. Chlorine dosage was based on maintaining a small chlorine residual in the filter effluent. Generally this was accomplished with 3.5 to 6.0 mg/l of chlorine applied.

A secondary effect of chlorination was disinfection of the effluent. A residual of 0.1 mg/l usually produced an effluent containing less than 10,000 fecal coliform per 100 ml. Of 18 observations in which there was a chlorine residual, the filter

effluent carried an average of 6,000 fecal coliform per 100 ml at an estimated detention time of 25 minutes. Overall secondary plant effluent varied during this time from 500,000 to 9,500,000 fecal coliform per 100 ml.

Removal of coliform in settling with alum coagulation does not appear to be reliable or effective. However, coliform reductions of up to 90% through the filters were observed. Fecal coliform load to the demonstration project ran from less than one million to 9.5 million per 100 ml.

pH adjustment has been recognized for many years as a method of disinfection and sterilization. Lime softening (pH 10.5) at Columbus, Ohio, using raw water from the Scioto River containing 300,000 B. Coli per 100 ml is reported to have reduced coliform counts to less than 1000 in five hours detention. B. Coli reduction was 100% effective with an excess lime dose of three grains per gallon.

Coliform reduction in lime softening of surface water supplies in Ohio reported by the National Lime Association* have been as follows:

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* Water Supply and Treatment, Ninth Edition, by Merrill Riehl, published by the National Lime Association, 1962.

	B. Coli per 100 ml		Total Detention
	Raw	Filtered	Time - Hours
Columbus	402	0.40	11.0
Fremont	3274	1.00	10.5
Greenville	1537	1.40	9.1
Newark	1376	0.40	23.2
Piqua	1004	0.30	11.5
Youngstown	6052	0.05	15.0

With a project influent averaging well above several million coliform per 100 ml and a detention time of 2½ hours, the following settled effluent fecal coliform concentrations were observed:

pH	B. Coli per 100 ml effluent	No. of Observations
9.0	800,000	2
9.2	27,500	1
9.5	64,500	5

While more work remains to be done, it appears that disinfection with high pH is a realistic possibility.

SPECIAL PROBLEMS

Four problems of major concern to design and operation of a tertiary treatment plant employing chemical treatment, sedimentation, and filtration were observed. These included foaming, scum formation, algae growth on the filters, and calcification of conduits.

While treating a good quality trickling filter effluent with alum and providing a high degree of BOD and suspended solids removal, a foam somewhat reminiscent of ABS was produced. It was characteristically white, relatively stable, and left a red, oily residue wherever it touched. Foaming occurred wherever the water was agitated, i.e., at the rapid mix, the flocculators, filter feed pump wet well, and on the filters. It appears that judiciously placed water sprays will knock down the foam to tolerable levels.

During high pH runs with lime, a thick scum was formed behind the baffle in the flocculator section. Among the possible causes are calcium precipitation of soluble potassium and sodium soaps, and calcium hydrolysis of fatty acids to form an insoluble calcium soap. The provision of surface skimming equipment in sedimentation should be adequate for control of this material in the settling tank.

After several months of rapid gravity filter operation it was observed that an algal-type slime was developing on the

filter media and was inhibiting the downward flow of water. An application of chlorine in the range of 3.5 to 5.0 mg/l of chlorine at the feed pump discharge successfully controlled the algae.

It was found that with the high pH lime treatment after several weeks the pressure pipes to the filters became calcified to the degree that capacity was lost. Recarbonation in the filter feed pump wet well will be tested in the future as a means of controlling calcification.

COST OF TERTIARY TREATMENT

The unit cost of providing tertiary treatment of the type studied in this project has been projected in three segments:

1. Capital costs
2. Operating and Maintenance costs
3. Chemical costs

In addition, comparison has been made of two basic operating schemes:

1. Chemical treatment, including coagulation, flocculation, and settling, and,
2. Chemical treatment, including coagulation, flocculation, and settling followed by rapid-sand filtration.

All estimates were based on current costs and no attempt has been made to project the costs to any future date.

Accommodation to Existing City of Dayton Treatment Plant

The City of Dayton wastewater plant currently has six 80 ft. diameter conventional final settling basins. In addition, four 120 ft. diameter basins equipped with flocculator-clarifier equipment will be placed in service in late 1969. Flow splitting units are being provided to accurately measure the flow to each of the new basins.

Facilities which would be needed to provide chemical treatment in the four new basins include chemical storage, chemical feed and pumping equipment, rapid mix basins, control monitoring

equipment, sludge recirculation units, and appropriate buildings. The estimated cost of these facilities is $200,000. The life of these facilities will average 20 years. Amortization over a 20 year period at 5½% will average $15,500 per year. For purposes of this report it was assumed that a 75 MGD sand filtration plant would be constructed with filter design loading at 2 gpm/sf with appropriate hydraulic features to accommodate all variations in plant load.

The cost of the 75 MGD filtration plant was estimated at $5,000,000 based on an average cost of four similarly sized plants constructed in 1963, cost updated by using Engineering News Record construction cost indexes. Assuming a bonded indebtedness based on 20 year bonds sold at 5½%, the average annual debt payment would be $387,500. Assuming no additional manpower or operating costs beyond that needed for chemical treatment would be required, the cost of rapid-sand filtration on a full time basis would cost $21.20 per million gallons. This cost per million gallons would necessarily rise with less than full time operation.

Labor to operate the chemical treatment facilities was estimated at $100,000 per year with an additional $50,000 per year for maintenance and utilities. The labor costs computed for the operation are considered to be adequate for chemical treatment alone or for the entire plant including rapid-sand

filtration. Certain economies may be possible in integrating this operation with other segments of the total plant operation.

Unit Cost Projections, Other than Chemicals, Assuming a 50 MGD Operation

Capital costs:

Chemical treatment facilities	$200,000	
$200,000 @ 5½% interest for 20 years	$310,000	
$\frac{\$310,000}{50 \text{ MGD} \times 20 \text{ years} \times 365 \text{ days/year}}$	=	$ 0.85/MG
Filtration Plant, complete	$5,000,000	
$5,000,000 @ 5½% interest for 20 years	$7,750,000	
$\frac{\$7,750,000}{50 \text{ MGD} \times 20 \text{ years} \times 365 \text{ days/year}}$	=	$21.20/MG
Operation:		
Manpower	$100,000/year	
Maintenance and Utilities	$ 50,000/year	
Total	$150,000/year	
$\frac{\$150,000/\text{year}}{50 \text{ MGD} \times 365 \text{ days/year}}$	=	$ 8.20/MG

Chemical Cost

BOD and phosphate removals will in all likelyhood be the major parameters considered in near-future effluent standards. While no effluent standards have yet been set, several recent studies have suggested that Dayton should at this time provide BOD removals of 90% or 95% with 97% in the next 10 to 20 years. The Ohio Water Pollution Control Board has recently adopted a requirement of 80% phosphate removals from domestic wastewater discharged to the feedwaters of Lake Erie and has indicated that this may be applied to all Ohio watersheds. Therefore, BOD reductions of 90%, 95%, and 97% and Phosphate reductions of 80% and 90% are felt to be a reasonable basis for comparison of chemical costs necessary to accomplish these reductions.

Chemical treatment costs to achieve these above goals are projected in the following tables. At this time a firm comparison of chemical costs between the various chemical combinations tested cannot be drawn. The alum and activated silica tests were performed using a significantly different quality effluent than that used while testing alum and the organic polyelectrolyte. The wastewater characteristics encountered during the lime tests was different from that encountered with either series of alum tests. These charts are included in order that this report will be complete.

Each chart represents the more economical combination of

chemical treatment and settling alone or chemical treatment in settling followed by rapid-sand filtration.

Chemical Combination	Chemical Cost $/MG	Cost of Chemical Treatment Capability $/MG	Cost of Sand Filtration Capability $/MG	Operating Cost $/MG	Total $/MG
		90% BOD Removal			
Alum + A-21*	-	-	-	-	-
Alum + SiO_2	12.00	0.85	-	8.20	21.05
Lime + A-21	13.25	0.85	21.20	8.20	43.50
Lime + SiO_2	12.60	0.85	-	8.20	21.65
Lime + $Fe_2(SO_4)_3$	11.75	0.85	21.20	8.20	42.00
		95% BOD Removal			
Alum + A-21*	-	-	-	-	-
Alum + SiO_2	25.25	0.85	-	8.20	34.30
Lime + A-21*	-	-	-	-	-
Lime + SiO_2	15.00	0.85	21.20	8.20	45.25
Lime + $Fe_2(SO_4)_3$	14.90	0.85	21.20	8.20	45.15
		97% BOD Removal			
Alum + A-21*	-	-	-	-	-
Alum + SiO_2	39.00	0.85	-	8.20	48.05
Lime + A-21*	-	-	-	-	-
Lime + SiO_2	18.50	0.85	21.20	8.20	48.75
Lime + $Fe_2(SO_4)_3$*	-	-	-	-	-
		80% Phosphate Removal			
Alum + A-21	35.75	0.85	-	8.20	44.80
Alum + SiO_2	46.75	0.85	-	8.20	55.80
Lime + A-21	15.35	0.85	-	8.20	24.40
Lime + SiO_2	10.50	0.85	-	8.20	19.55
Lime + $Fe_2(SO_4)_3$	12.50	0.85	-	8.20	21.55
		90% Phosphate Removal			
Alum + A-21	34.35	0.85	21.20	8.20	64.60
Alum + SiO_2	51.75	0.85	21.20	8.20	82.00
Lime + A-21	22.40	0.85	-	8.20	31.45
Lime + SiO_2	13.60	0.85	-	8.20	22.65
Lime + $Fe_2(SO_4)_3$	19.00	0.85	-	8.20	28.05

* Insufficient data for estimating.

CONCLUSIONS

The number of variables in the wastewater treatment system makes very difficult the task of isolating meaningful relationships and drawing final conclusions based on the period of time of the operation covered in this report. However, for the purpose of reporting progress during the period of time that the project was in part financed by an FWPCA Demonstration Project Grant the following conclusions are offered:

1. Conventional water treatment procedures using coagulation, flocculation, and rapid-sand filtration offer the City of Dayton a sound means of achieving extremely good effluent quality from a trickling filter waste treatment plant.

2. A high degree of phosphate removal is achievable with chemical coagulation and settling without the final polish of rapid-sand filtration.

3. While removal efficiencies for both pilot plant filters are approximately the same, the dual media filter has achieved better overall performance than the single media sand filter.

4. Chemical coagulation and flocculation before final settling offer a flexible means of significantly improving effluent quality over plain settling. Facilities to achieve the improvement are relatively modest in cost. The chemical

additions, although costly, may be tailored to fit seasonal needs, flow variations, and unusual demands.

5. A one-step chemical treatment process has not been shown to be a substitute for good biological treatment.

6. The cost of chemical treatment before final settling may approach or even exceed the costs of primary and secondary wastewater treatment.

7. Any scheme of enhancement of the secondary plant effluent would appear to require chemical treatment as a part of the process. Rapid-sand filtration alone without prior chemical treatment would not appear to offer a sound return on investment.

8. Any scheme of tertiary treatment using chemicals and rapid-sand filtration must be evaluated considering the total picture including the problems of sludge and backwash water. The period of operation of this project has not provided data for comparative evaluation of these factors.

9. To be truly valid, demonstration of any given technique must be programmed over at least a 12 month period in order to verify the technique over the full range of plant influent and treatment variations.

ACKNOWLEDGEMENTS

This project was in part supported by a Demonstration Project Grant, Federal Water Pollution Control Administration, Department of Interior.

Grateful acknowledgements are extended to each of the many persons who had a part in the development, programming, and performance of the demonstration work.

Key members of the plant staff who have been involved are Resler H. Calihan, Technical Supervisor, Ronald F. Scott, Wastewater Treatment Specialist, Paul J. Fleming, Engineer, and Bonnie Cowley, Clerk-Typist. Coordination of field construction and operation was handled principally by Mr. Scott throughout the term of the study.

Plant Supervisors Ralph R. Kendig and Hampton L. Wolfe were of invaluable aid in the construction and maintenance of the equipment and in assisting in coordinating the project operation with regular plant operation. Their many employees exhibited great interest and diligence in various assignments connected with the project.

Special recognition is extended to Paul Haney, Partner, Black and Veatch Consulting Engineers, for his assistance in formulation of the program, monitoring of the work, and critical evaluation of the interpretation of observed data.

Authority for undertaking the project was granted by the City Commission, City Manager, and Director of Water. The vital interest, assistance, and departmental direction given the project by W. T. Eiffert, Director of Water, has aided much in the progress of the work.

DeFro Tossey
Project Director
Superintendent of Sewage Treatment

APPENDIX A

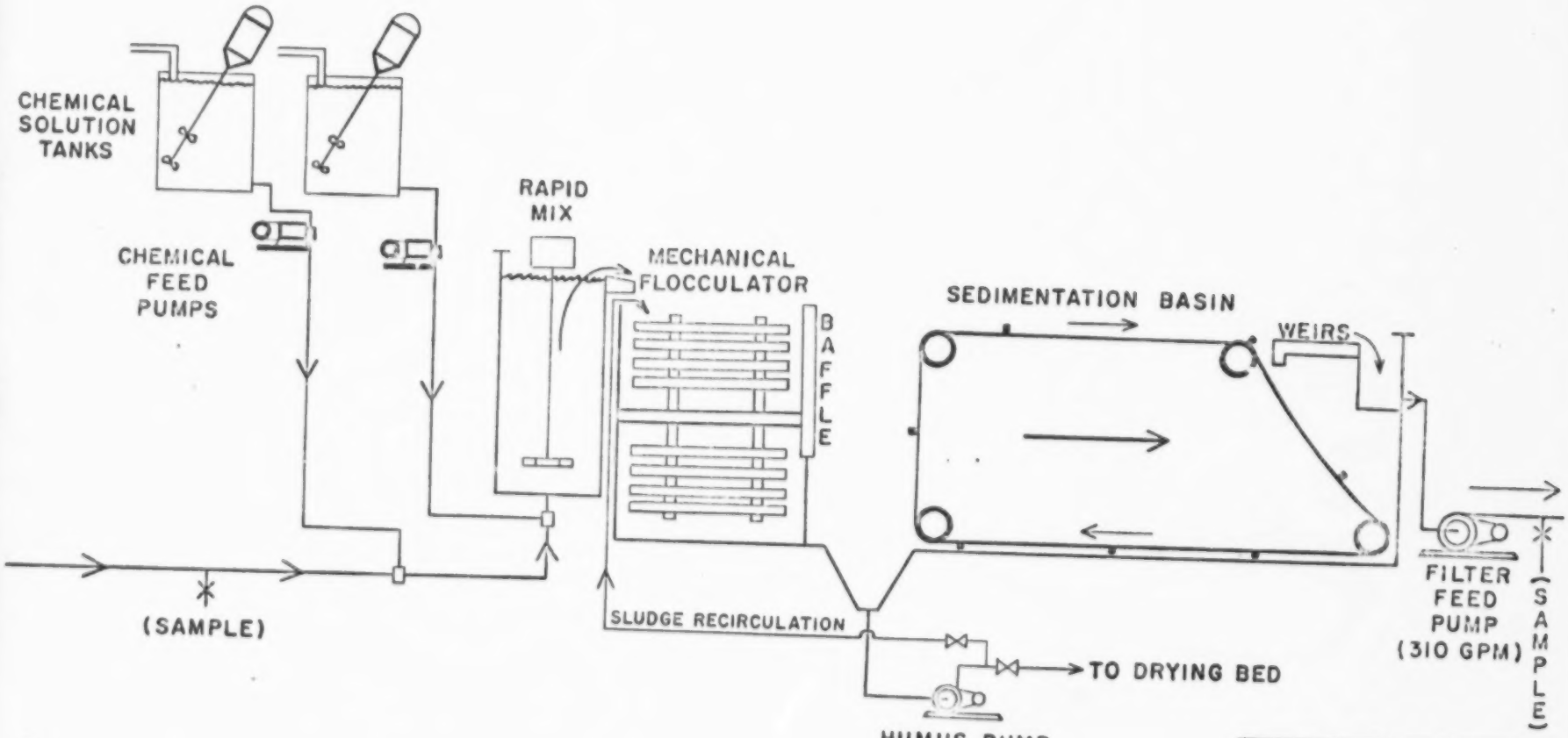
GRAPHICAL ANALYSIS AND INTERPRETATION OF DATA

FIGURE	DESCRIPTION
1	Demonstration Project Sedimentation Basin
2	Demonstration Project Rapid-Sand Filters
3	Flow vs. Surface Overflow Rate - Settling Basin
4	Flow vs. Detention Time - Settling Basin
5	BOD_5 Removal with Alum + SiO_2 (at 9.5% of Alum) Surface Overflow: 950 to 1035 gpd/sf
6	BOD_5 Removals with Alum + SiO_2 Surface Overflow: 655 to 835 gpd/sf
7	BOD_5 Removal with Alum using 1.0 mg/l A-21 Surface Overflow: 850 to 1035 gpd/sf
8	BOD_5 Reduction in Settling at Various Alum to Influent BOD_5 Ratios - Alum + Activated Silica - Surface Overflow: 950 to 1035 gpd/sf
9	BOD_5 Reductions in Settling at Various Alum to Influent BOD_5 Ratios - Alum + Activated Silica Surface Overflow: 655 to 835 gpd/sf
10	BOD_5 Reduction in Settling at Various Alum to Influent BOD_5 Ratios - Alum + Dow A-21 Surface Overflow: 850 to 1035 gpd/sf
11	Family of Curves showing BOD_5 Reductions at Various Alum Dosages in Settling - Alum + Dow A-21 Surface Overflow: 850 to 1035 gpd/sf
12	Reduction of BOD_5 using Lime + 1.0 mg/l A-21 Surface Overflow: 988 gpd/sf
13	Reduction of BOD_5 with Lime + 2.0 mg/l SiO_2 Surface Overflow Rate: 966 gpd/sf
14	BOD_5 Reduction with Lime + Ferric Sulfate (20 mg/l) with Sludge Recirculation
15	BOD_5 Reduction vs. Ratio of CaO Applied to Influent BOD_5 - Dow A-21 Floc Aid

FIGURE	DESCRIPTION
16	BOD_5 Reduction in Settling vs. Ratio of CaO Applied to Influent BOD_5 - Activated Silica Flocculant Aid
17	BOD_5 Reduction in Settling vs. Ratio of CaO Applied to Influent BOD_5 - Ferric Sulfate Flocculant Aid
18	Family of Curves showing Suspended Solids Reductions at Various Lime Dosages in Settling - Dow A-21 Flocculant Aid
19	Suspended Solids Removal with Alum + SiO_2 (at 9.5% of Alum) Surface Overflow: 950 to 1035 gpd/sf
20	Suspended Solids Reduction with Alum + SiO_2 (at 9.5% of Alum) Surface Overflow: 655 to 835 gpd/sf
21	Suspended Solids Removal with Alum using 1.0 mg/l A-21 - Surface Overflow Rates: 850 to 1035 gpd/sf
22	Suspended Solids Reductions in Settling at Various Alum to Suspended Solids Influent Ratios - Alum + Activated Silica - Surface Overflow: 950 to 1035 gpd/sf
23	Suspended Solids Reductions in Settling at Various Alum to Influent Suspended Solids Ratios - Activated Silica Flocculant Aid - Surface Overflow: 655 to 835 gpd/sf
24	Suspended Solids Reduction vs. Ratio of Alum to Influent Suspended Solids using Dow A-21 Flocculant Aid - Surface Overflow: 850 to 1035 gpd/sf
25	Family of Curves showing Suspended Solids Reductions with Alum - Dow A-21 Flocculant Aid - Surface Overflow: 850 to 1035 gpd/sf
26	Reduction of Suspended Solids - Lime Treatment with 1.0 mg/l A-21 - Settling Tank Surface Overflow: 988 gpd/sf
27	Reduction of Suspended Solids with Lime + 2.0 mg/l SiO_2 - Settling Tank Surface Overflow: 966 gpd/sf

FIGURE	DESCRIPTION
28	Suspended Solids Reductions with Lime + Ferric Sulfate 20 mg/l with Sludge Recirculation
29	Suspended Solids Reduction vs. Ratio of CaO Applied to Influent Suspended Solids - Dow A-21 Flocculant Aid
30	Suspended Solids Reduction in Settling vs. Ratio of CaO Applied to Influent Suspended Solids - Activated Silica Flocculant Aid
31	Suspended Solids Reductions vs. Ratio of Lime Dose to Suspended Solids Loading - Ferric Sulfate Flocculant Aid
32	Phosphate Removal with Alum Treatment using SiO_2 (at 9.5% of Alum) Flocculant Aid - Surface Overflow: 950 to 1035 gpd/sf
33	Phosphate Removal with Alum + SiO_2 (at 9.5% of Alum) Surface Overflow: 655 to 835 gpd/sf
34	PO_4^{---} Removal with Alum using 1.0 mg/l A-21 Surface Overflow: 850 to 1035 gpd/sf
35	Reduction of Phosphate (PO_4^{---}) with Lime and 1.0 mg/l A-21 - Settling Tank Surface Overflow: 988 gpd/sf
36	Reduction of Phosphate (PO_4^{---}) with Lime + 2.0 mg/l SiO_2 - Settling Tank Surface Overflow: 966 gpd/sf
37	Phosphate Reduction with Lime + Ferric Sulfate (20 mg/l) with Sludge Recirculation
38	Ratio of Phosphate Removed to Alum Applied vs. Phosphate Residual - Activated Silica Flocculant Aid Surface Overflow: 950 to 1035 gpd/sf
39	Ratio of Phosphate Removed to Alum Applied vs. Phosphate Residual - Activated Silica Flocculant Aid Surface Overflow: 655 to 835 gpd/sf
40	Ratio of Phosphate Removed to Alum Applied vs. Phosphate Residual in Effluent - Dow A-21 Flocculant Aid
41	Phosphate Residual vs. Ratio of Phosphate Removed to CaO Applied - Dow A-21 Flocculant Aid

FIGURE	DESCRIPTION
42	Phosphate Residual vs. Ratio of PO_4^{---} Removed to CaO Applied - Activated Silica Flocculant Aid
43	Phosphate Residual vs. Ratio of PO_4^{---} Removed to CaO Applied - Ferric Sulfate Flocculant Aid
44	Chemical Cost to Treat 1 MG of Wastewater at Various Chemical Feed Rates - 1969 Prices



PROCESS UNIT	AT 310 GPM DETENTION TIME	AT 310 GPM SURFACE OVERFLOW
RAPID MIX	1.35 MIN.	———
FLOCCULATION	39 MIN.	———
SEDIMENTATION	105 MIN.	1014 GAL/FT^2/DA.

DAYTON, OHIO
DEMONSTRATION PROJECT
SEDIMENTATION BASIN

FIGURE 1

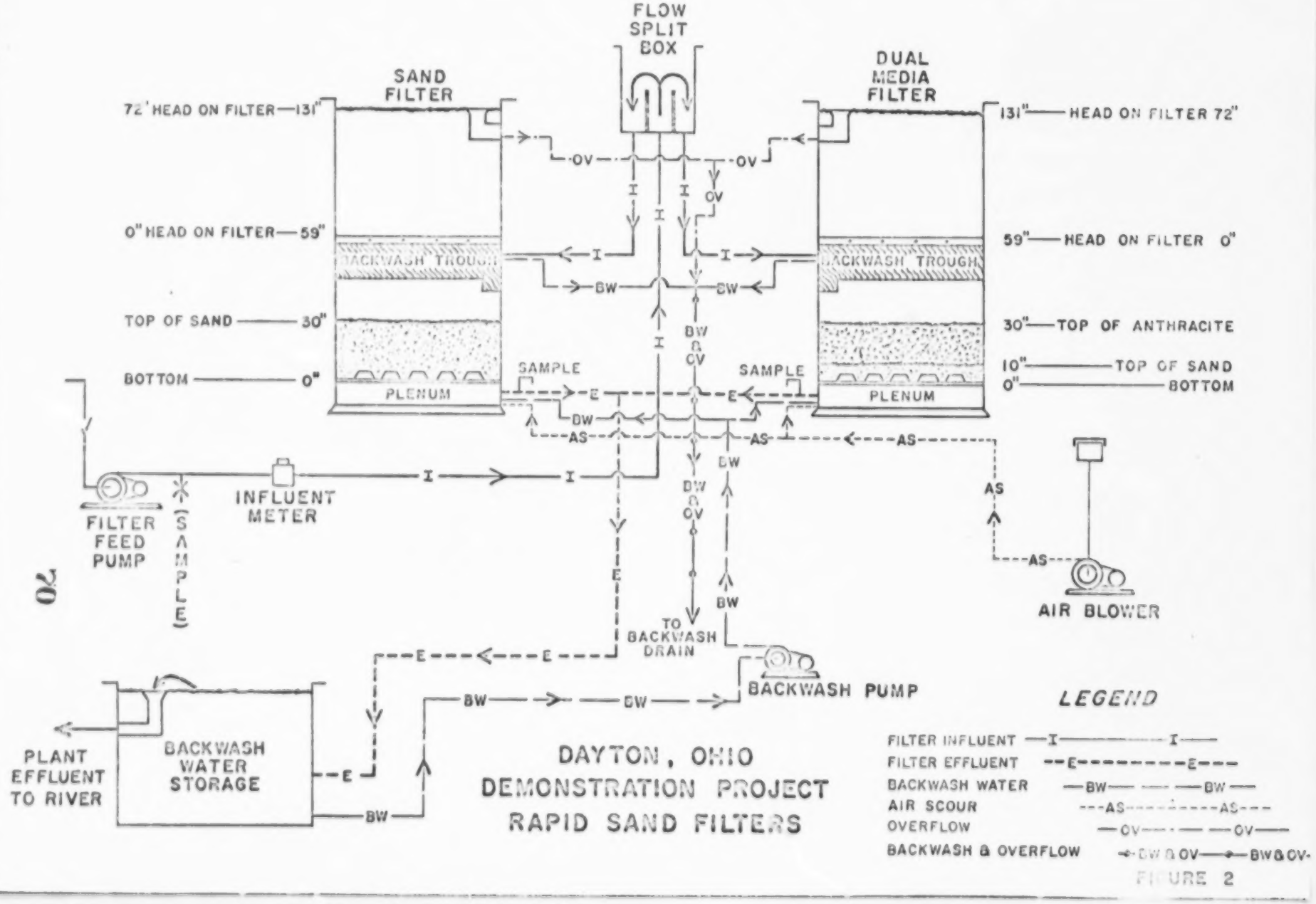

FLOW SPLIT BOX
SAND FILTER
DUAL MEDIA FILTER
72" HEAD ON FILTER — 131"
131" — HEAD ON FILTER 72"
0" HEAD ON FILTER — 59"
59" — HEAD ON FILTER 0"
TOP OF SAND — 30"
30" — TOP OF ANTHRACITE
BOTTOM — 0"
10" — TOP OF SAND
0" — BOTTOM
BACKWASH TROUGH
PLENUM
SAMPLE
OV
I
BW
BW & OV
E
AS
DW
DW & OV
FILTER FEED PUMP
SAMPLE
INFLUENT METER
AIR BLOWER
TO BACKWASH DRAIN
BACKWASH PUMP
PLANT EFFLUENT TO RIVER
BACKWASH WATER STORAGE
DAYTON, OHIO
DEMONSTRATION PROJECT
RAPID SAND FILTERS
LEGEND
FILTER INFLUENT
FILTER EFFLUENT
BACKWASH WATER
AIR SCOUR
OVERFLOW
BACKWASH & OVERFLOW
BW & OV
BW & OV

FIGURE 2

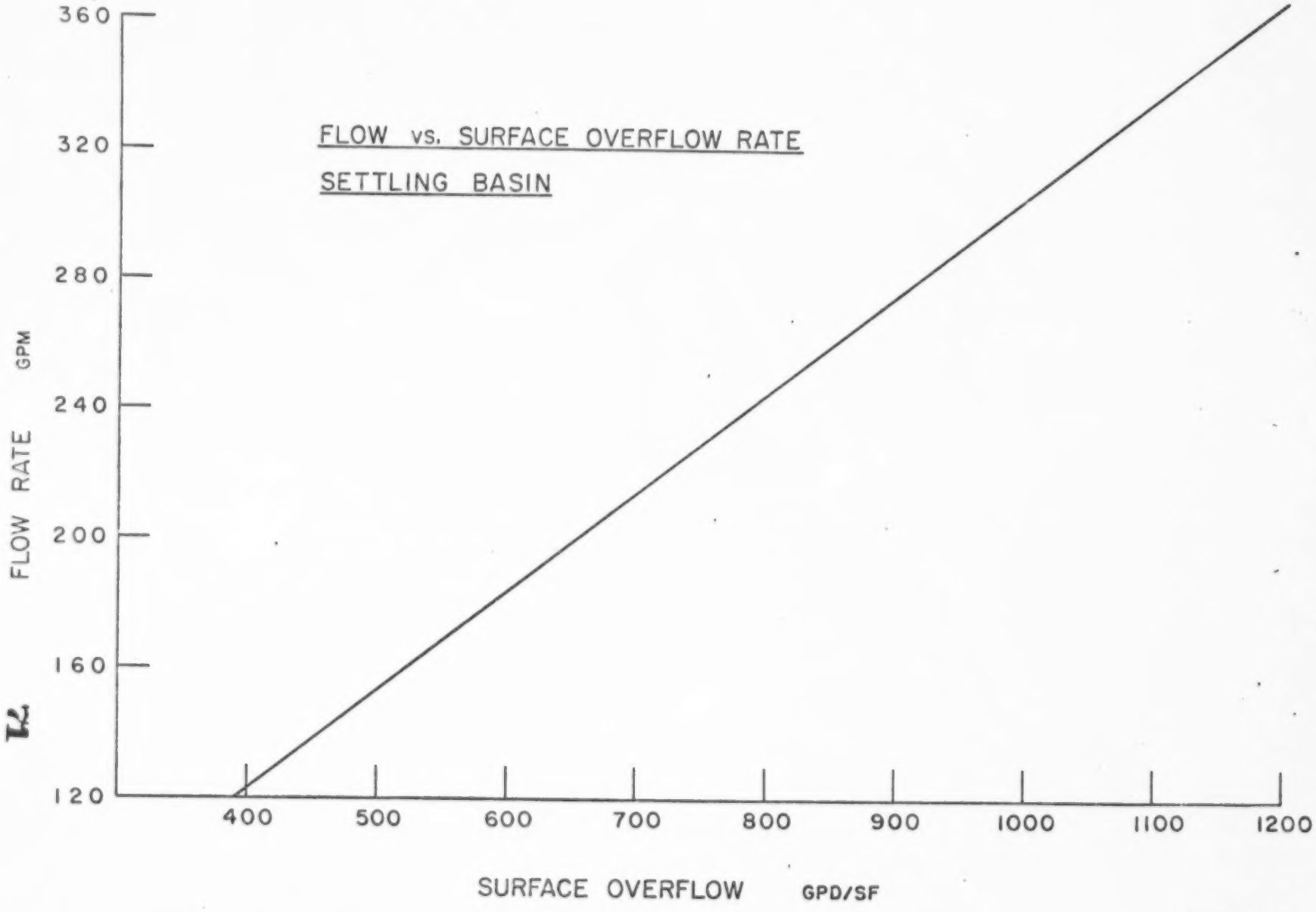

FLOW vs. SURFACE OVERFLOW RATE
SETTLING BASIN
360
320
280
240
200
160
120
FLOW RATE GPM
400
500
600
700
800
900
1000
1100
1200
SURFACE OVERFLOW GPD/SF

FIGURE 3

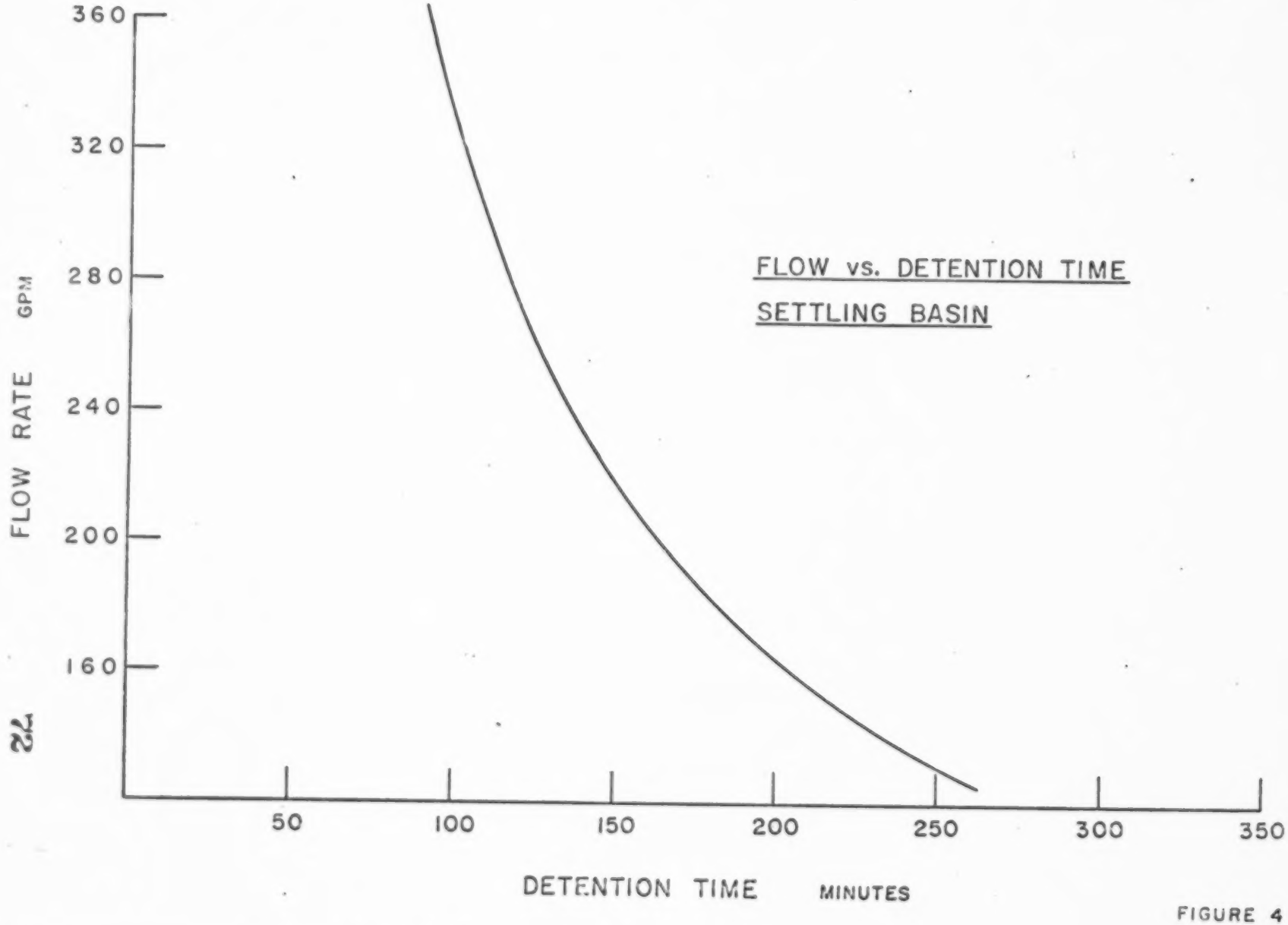

360
320
280
240
200
160
FLOW RATE GPM
50
100
150
200
250
300
350
DETENTION TIME MINUTES
FLOW vs. DETENTION TIME
SETTLING BASIN

FIGURE 4

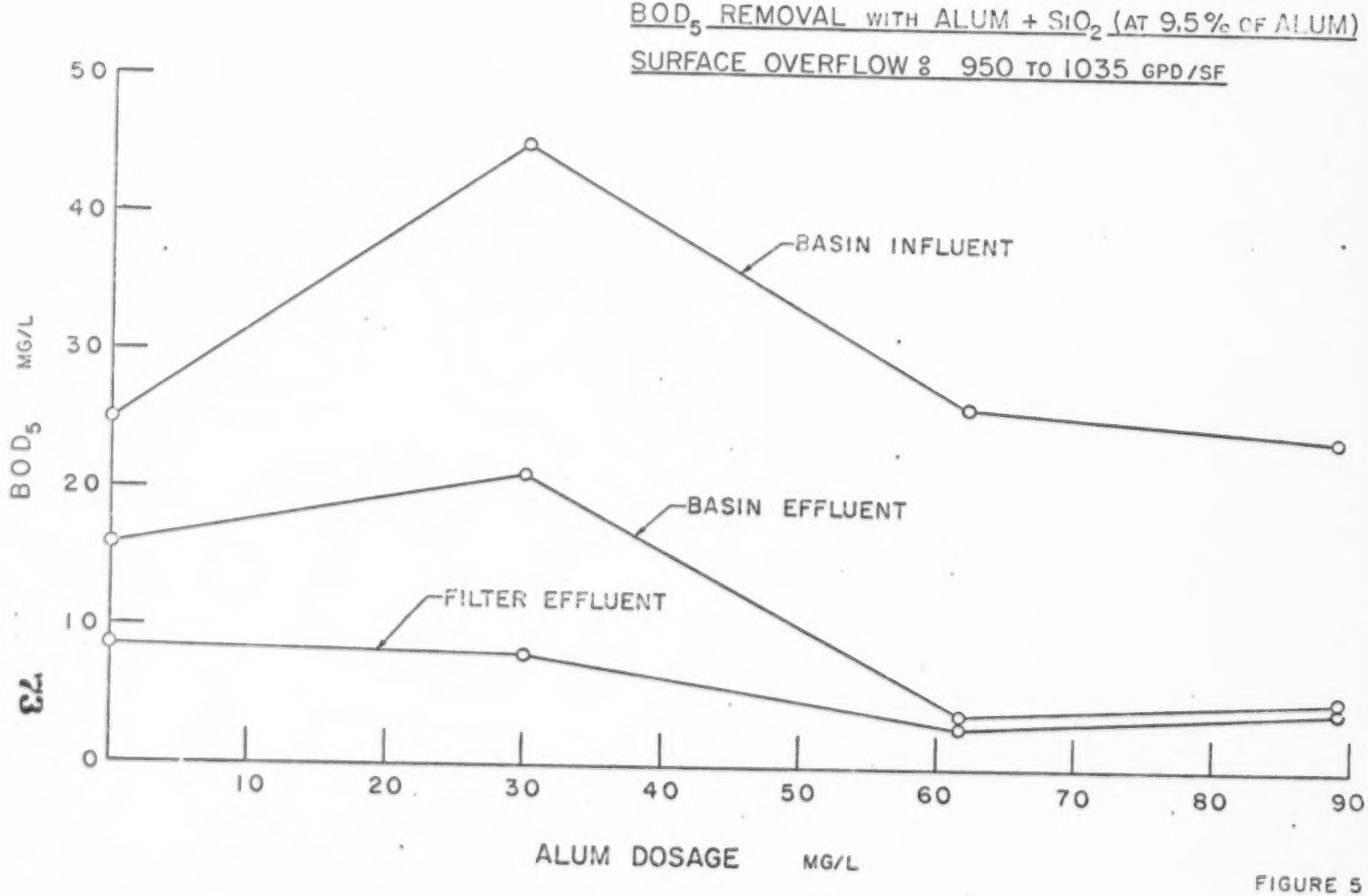

BOD5 REMOVAL WITH ALUM + SiO2 (AT 9.5% OF ALUM)
SURFACE OVERFLOW @ 950 TO 1035 GPD/SF
BOD5 MG/L
50
40
30
20
10
0
BASIN INFLUENT
BASIN EFFLUENT
FILTER EFFLUENT
10
20
30
40
50
60
70
80
90
ALUM DOSAGE MG/L

FIGURE 5

BOD_5 REMOVALS WITH ALUM + SiO_2

SURFACE OVERFLOWS 655 TO 835 GPD/SF

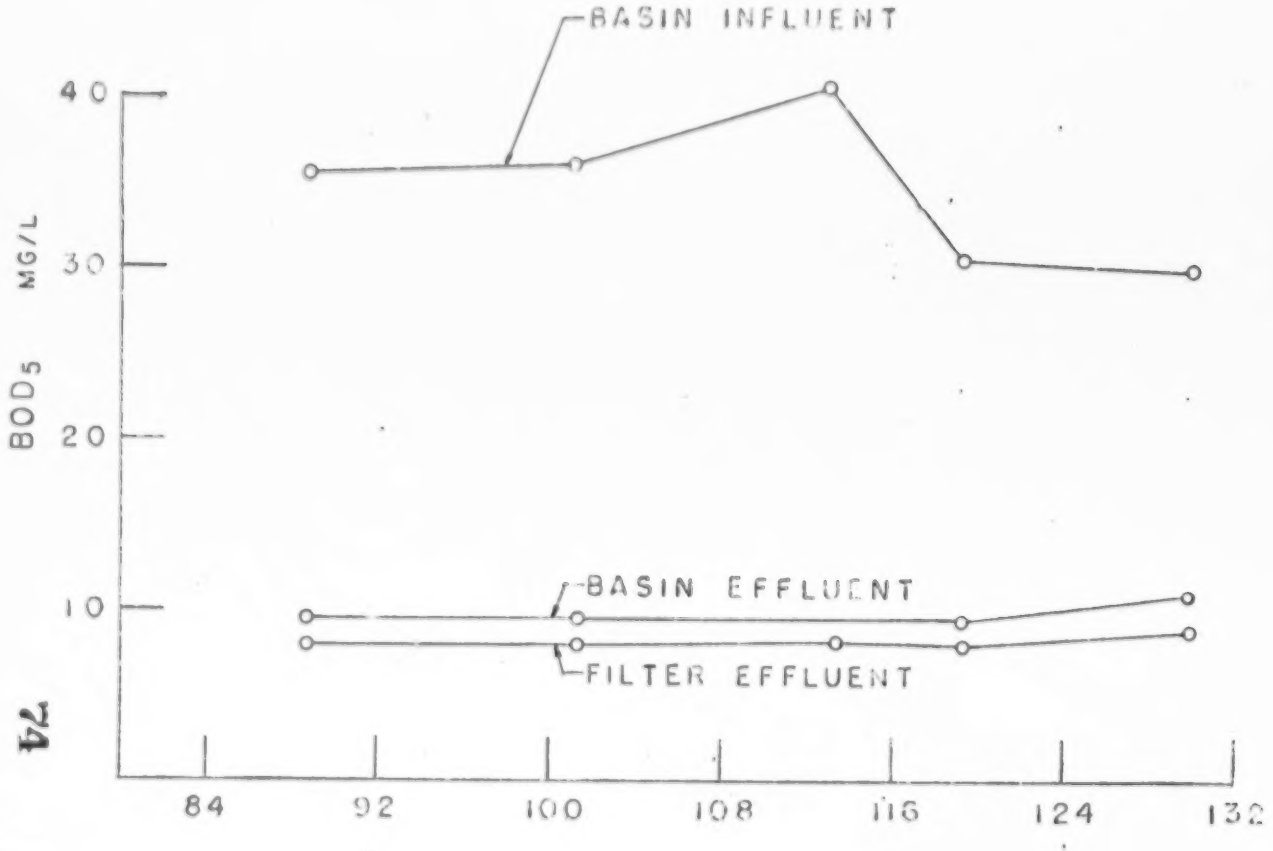


FIGURE 6

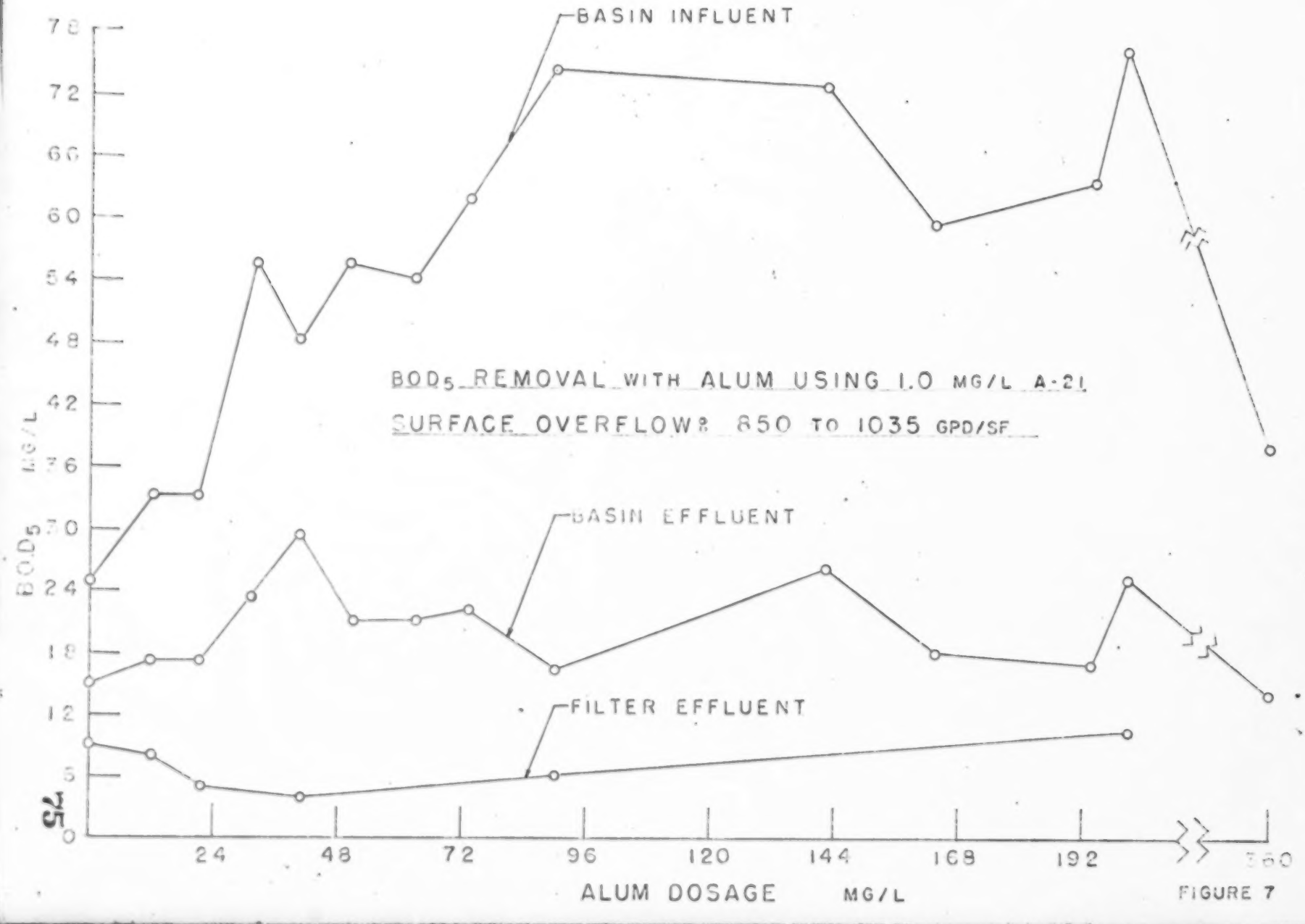

BASIN INFLUENT
BOD5 REMOVAL WITH ALUM USING 1.0 MG/L A-21
SURFACE OVERFLOWS 850 TO 1035 GPD/SF
BASIN EFFLUENT
FILTER EFFLUENT
BOD5 MG/L
78
72
66
60
54
48
42
36
30
24
18
12
6
0
24
48
72
96
120
144
168
192
360
ALUM DOSAGE MG/L

FIGURE 7

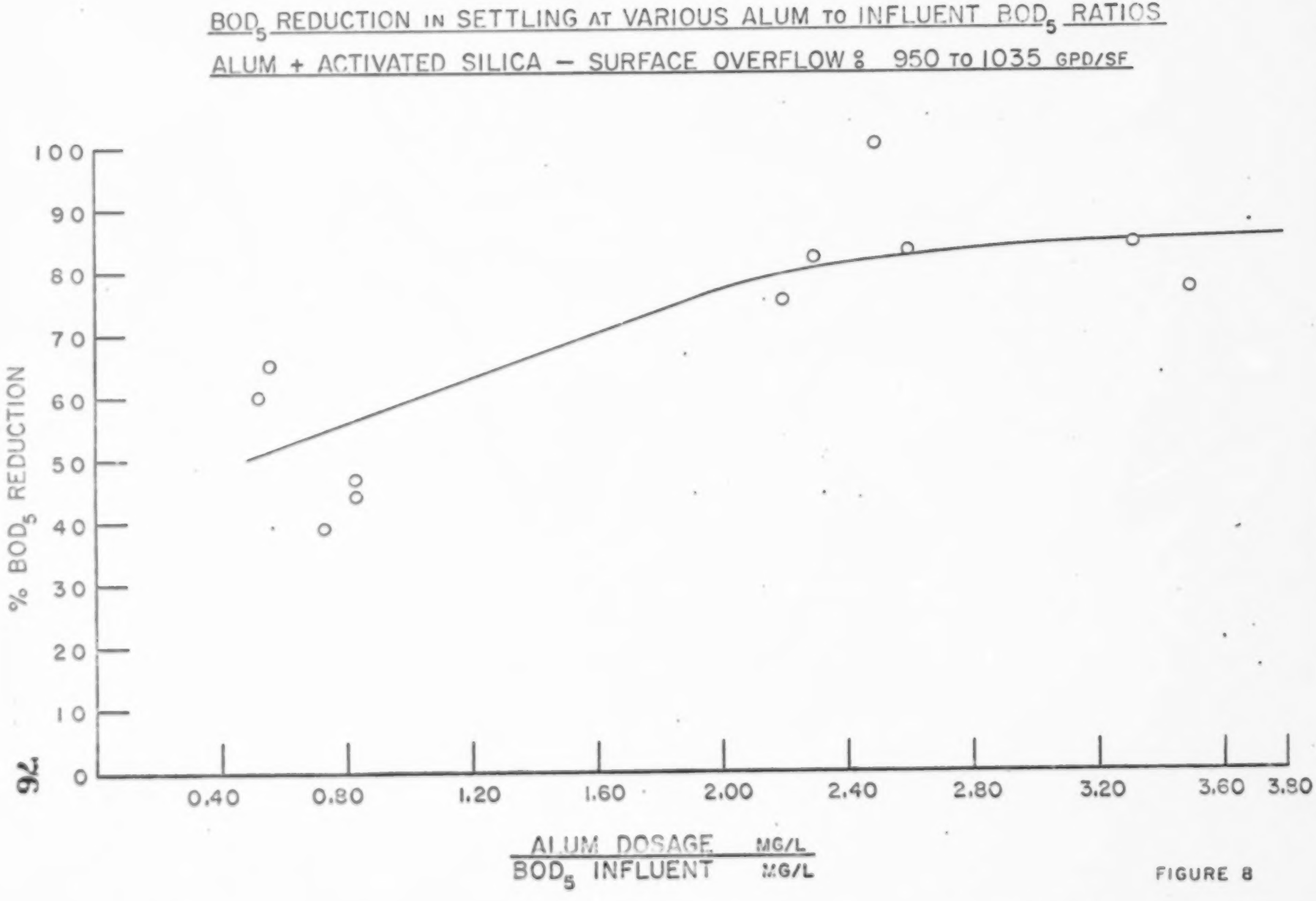

BOD5 REDUCTION IN SETTLING AT VARIOUS ALUM TO INFLUENT BOD5 RATIOS
ALUM + ACTIVATED SILICA – SURFACE OVERFLOW @ 950 TO 1035 GPD/SF
% BOD5 REDUCTION
100
90
80
70
60
50
40
30
20
10
0
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
3.80
ALUM DOSAGE MG/L
BOD5 INFLUENT MG/L

FIGURE 8

BOD_5 REDUCTIONS IN SETTLING AT VARIOUS ALUM TO INFLUENT BOD_5 RATIOS

ALUM + ACTIVATED SILICA

SURFACE OVERFLOW @ 655 TO 835 GPD/SF

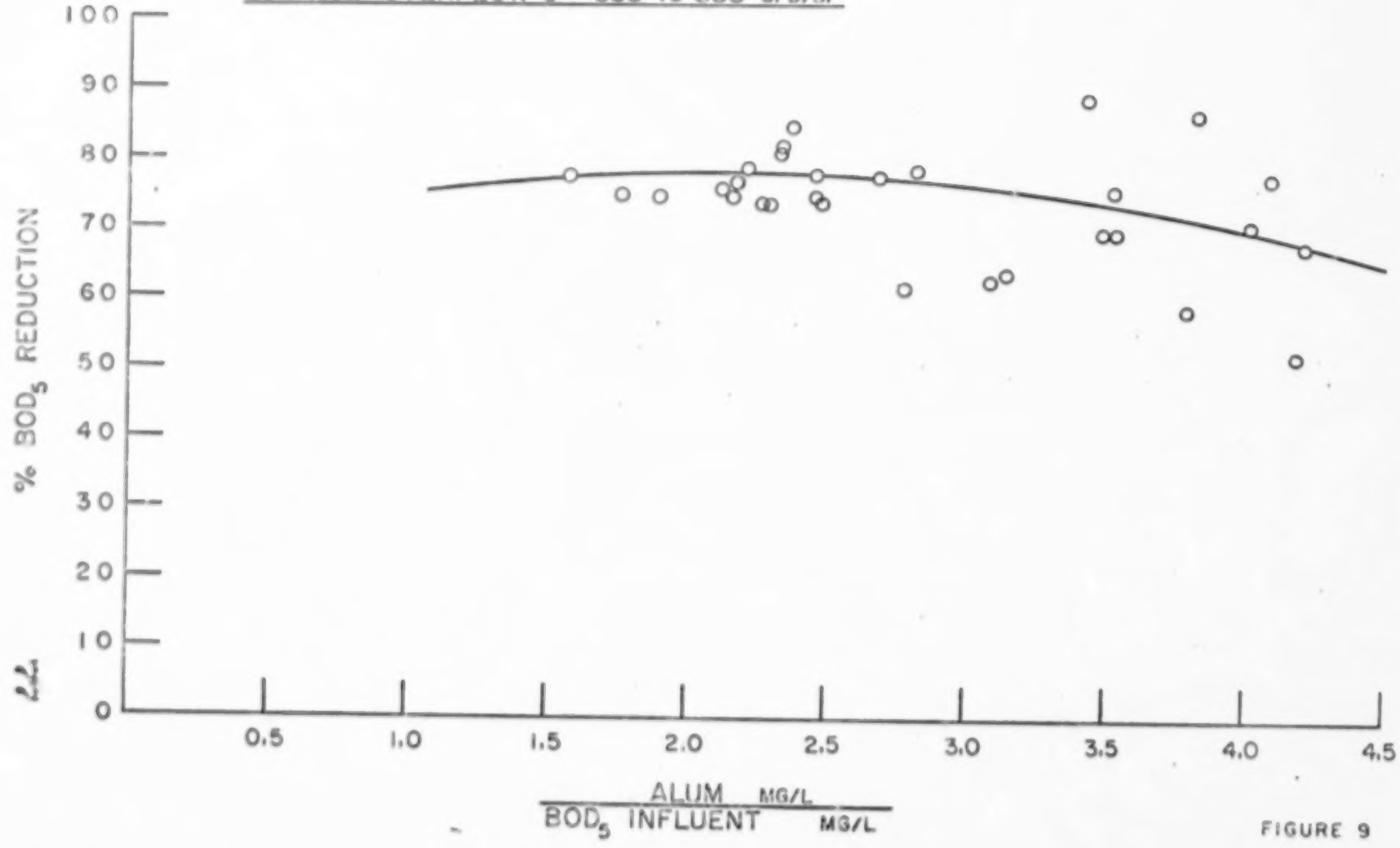


FIGURE 9

BOD_5 REDUCTION IN SETTLING AT VARIOUS ALUM TO INFLUENT BOD_5 RATIOS ALUM + DOW A-21
SURFACE OVERFLOW 850 TO 1035 GPD/SF

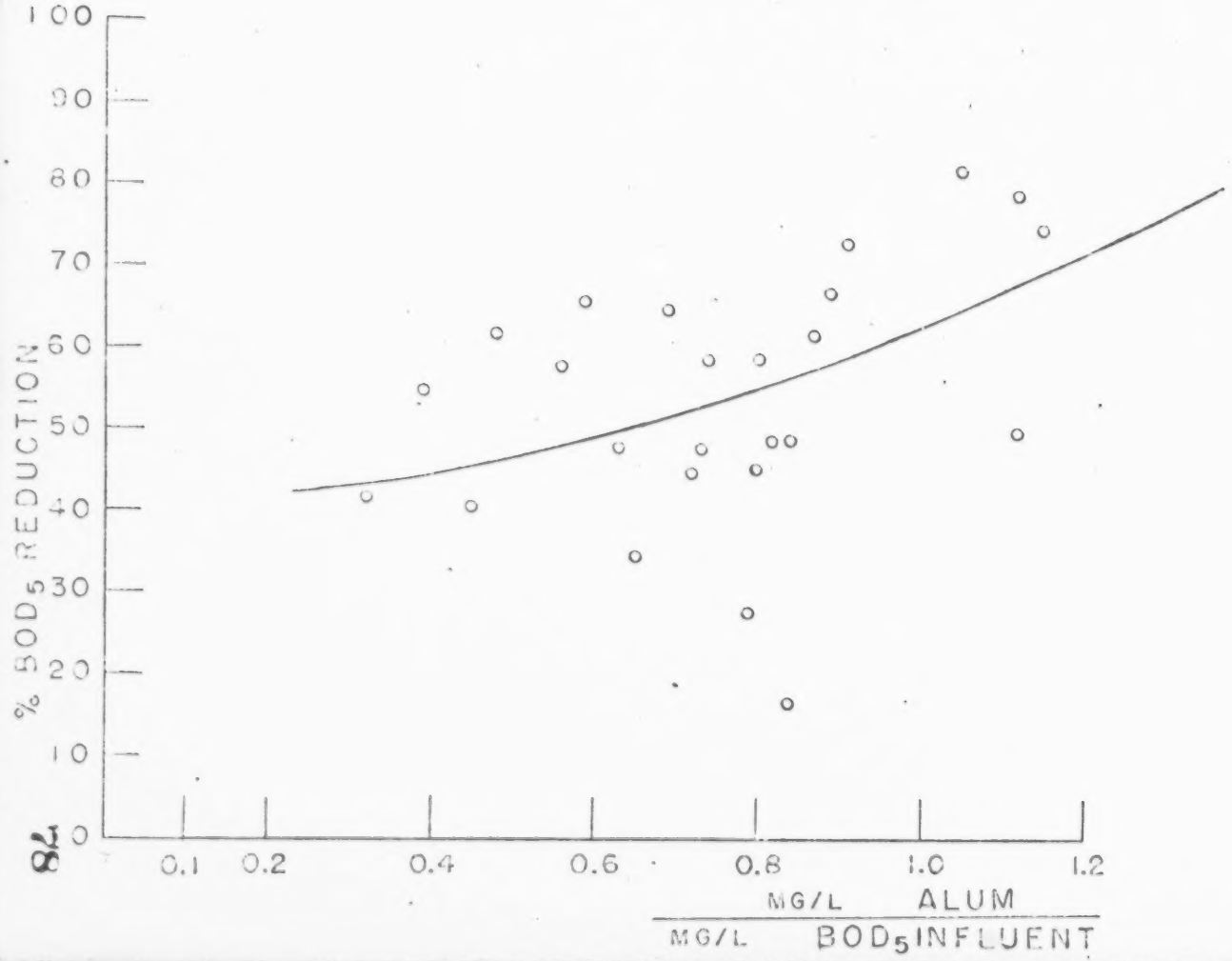


FIGURE 10

FAMILY OF CURVES SHOWING BOD_5 REDUCTIONS AT VARIOUS ALUM DOSAGES IN SETTLING – ALUM + DOW A-21
SURFACE OVERFLOW 850 TO 1035 GPD/SF

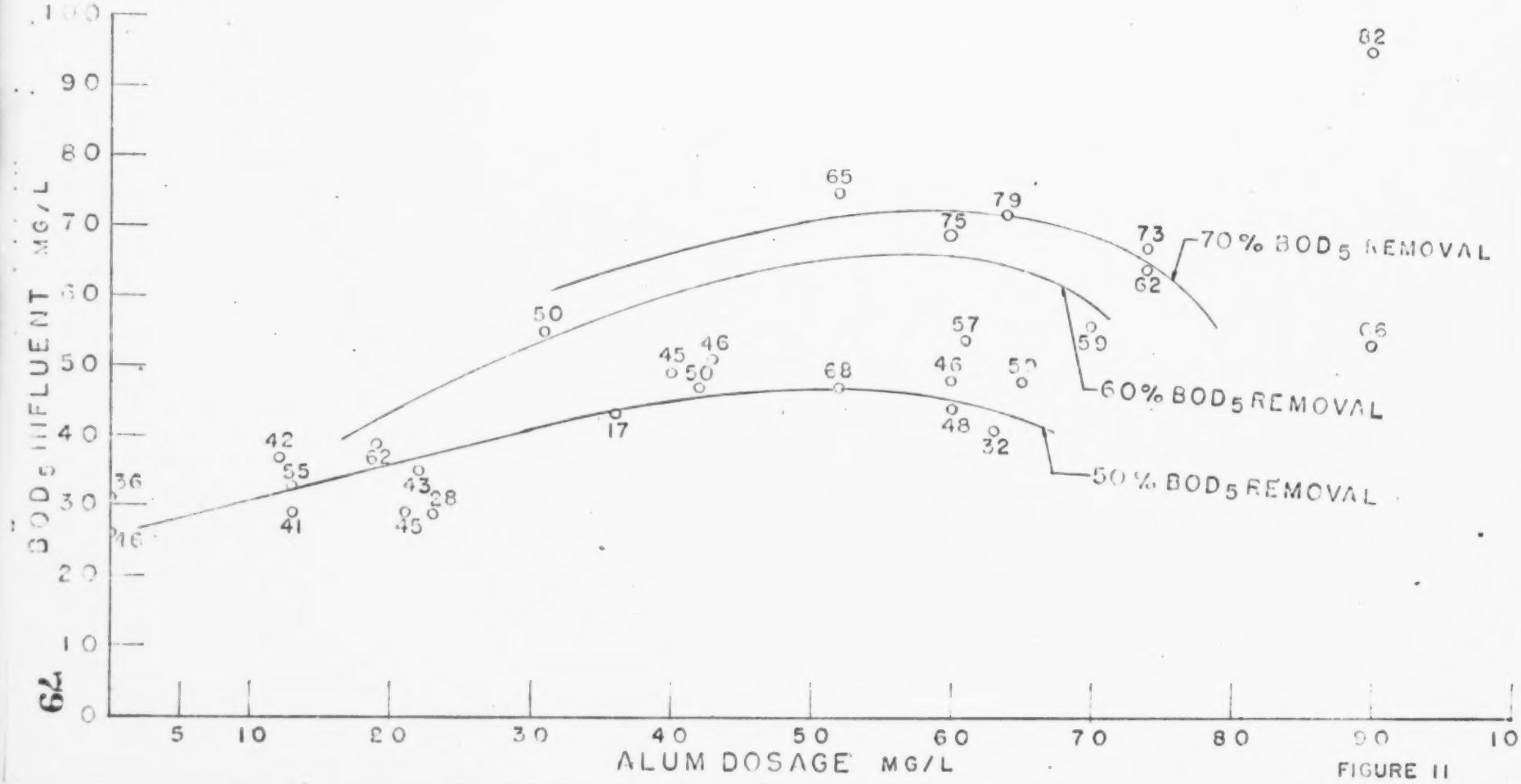


FIGURE 11

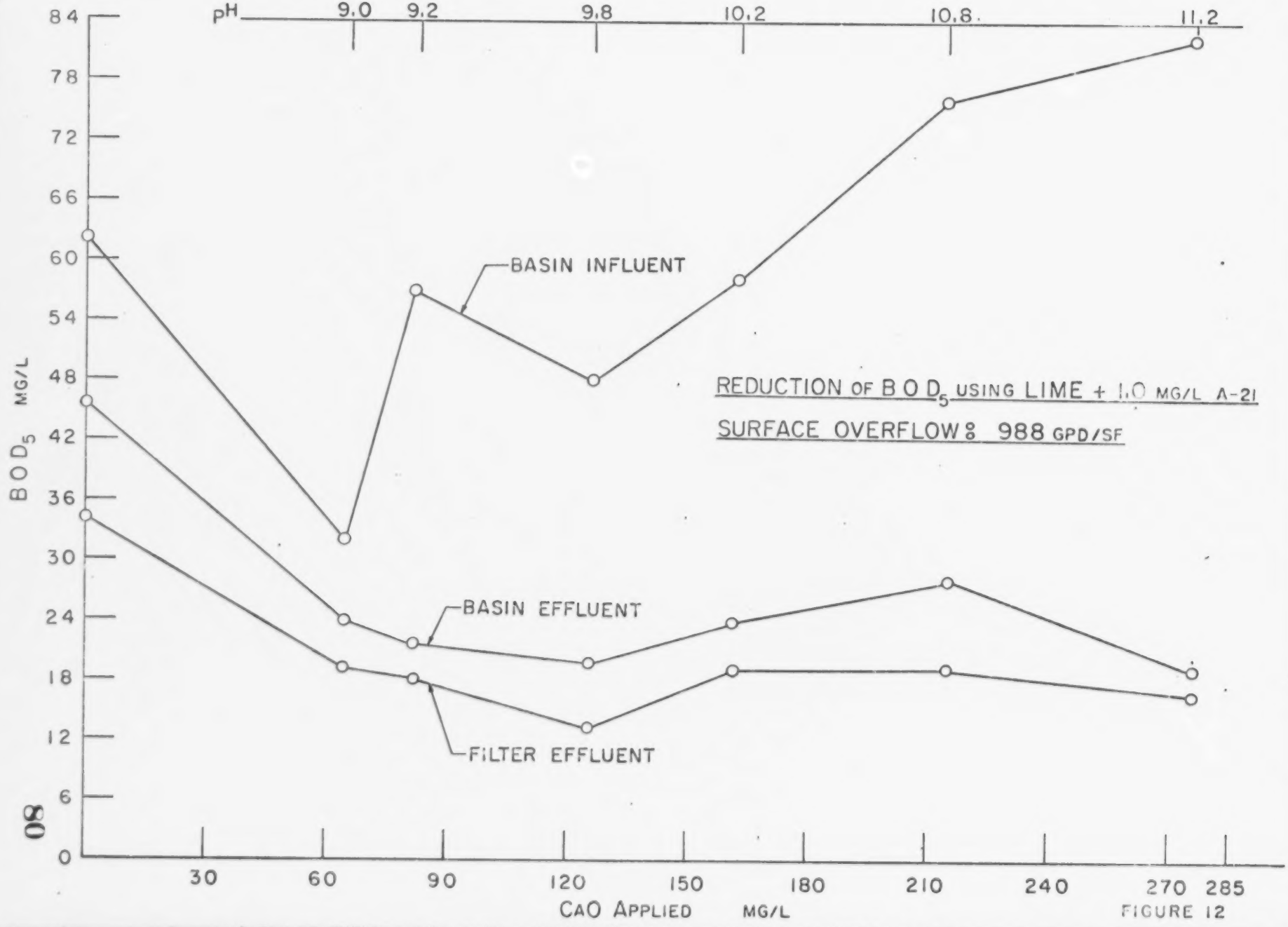

pH
9.0
9.2
9.8
10.2
10.8
11.2
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
BOD5 MG/L
BASIN INFLUENT
BASIN EFFLUENT
FILTER EFFLUENT
REDUCTION OF BOD5 USING LIME + 1.0 MG/L A-21
SURFACE OVERFLOW @ 988 GPD/SF
30
60
90
120
150
180
210
240
270
285
CaO APPLIED MG/L

FIGURE 12

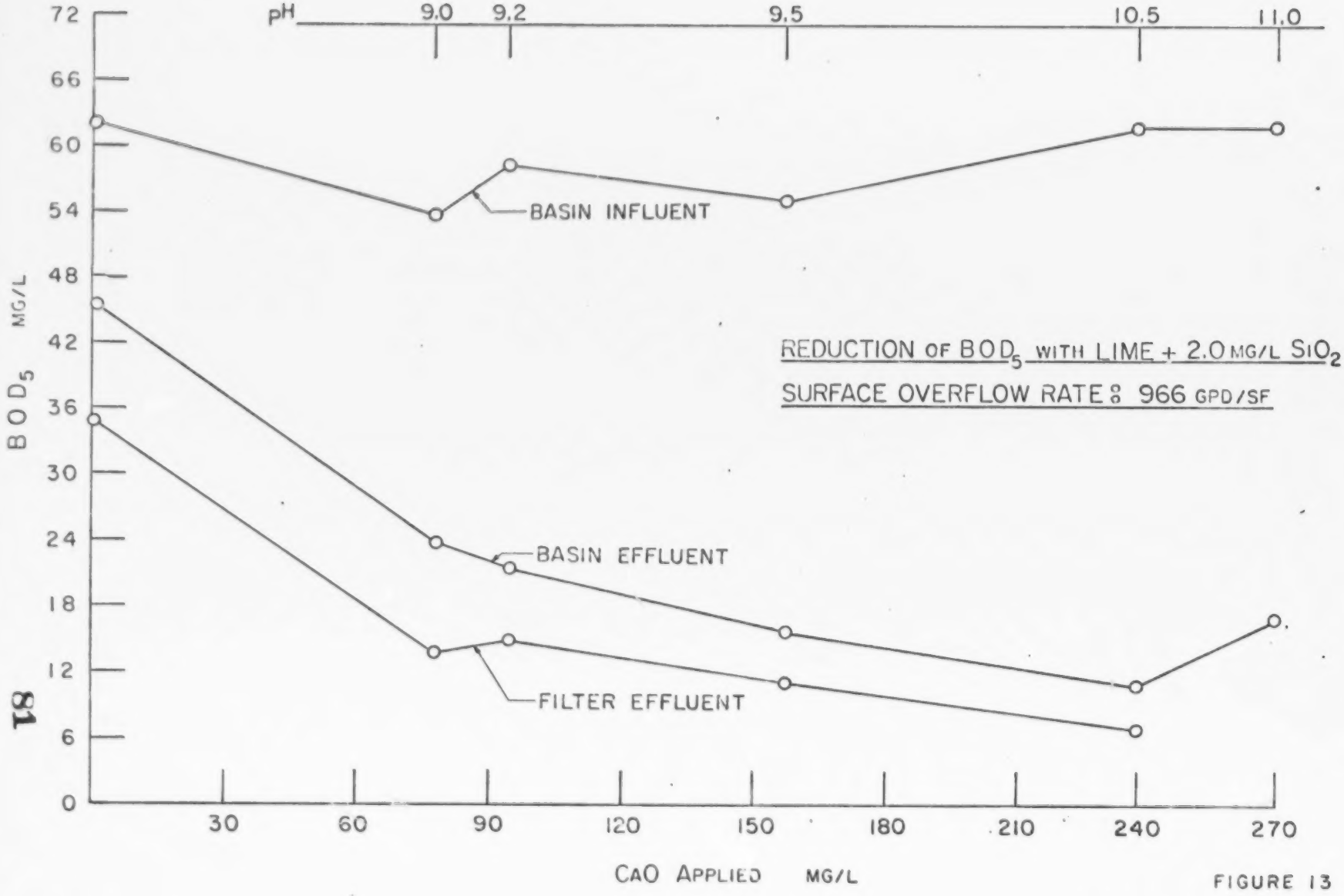

pH
9.0
9.2
9.5
10.5
11.0
72
66
60
54
48
42
36
30
24
18
12
6
0
BOD5 MG/L
BASIN INFLUENT
BASIN EFFLUENT
FILTER EFFLUENT
REDUCTION OF BOD5 WITH LIME + 2.0 MG/L SiO2
SURFACE OVERFLOW RATE @ 966 GPD/SF
30
60
90
120
150
180
210
240
270
CaO APPLIED MG/L

FIGURE 13

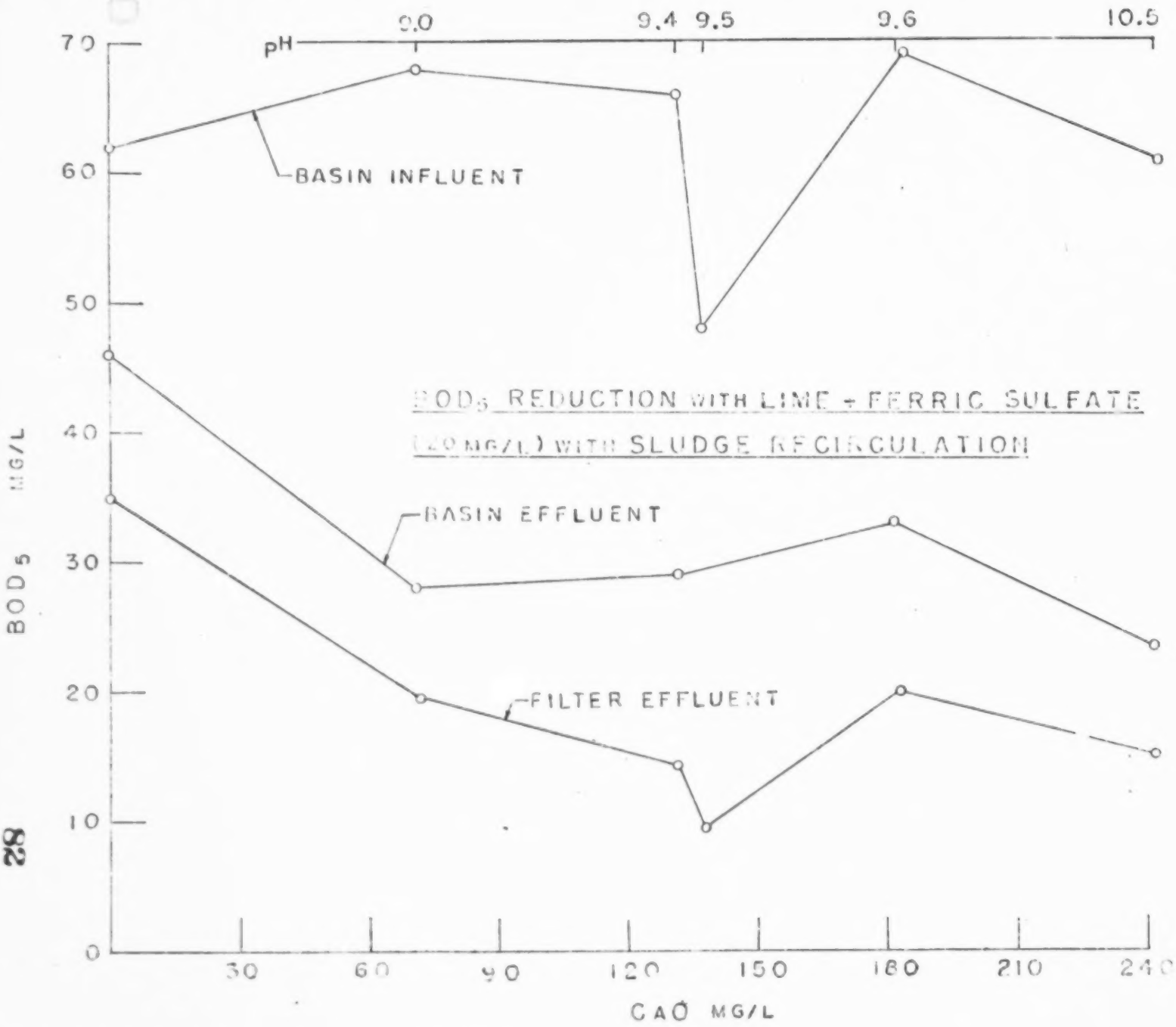

pH
9.0
9.4
9.5
9.6
10.5
70
60
50
40
30
20
10
0
BASIN INFLUENT
BOD5 REDUCTION WITH LIME + FERRIC SULFATE
(20 MG/L) WITH SLUDGE RECIRCULATION
BASIN EFFLUENT
FILTER EFFLUENT
BOD5 MG/L
30
60
90
120
150
180
210
240
CaO MG/L

FIGURE 14

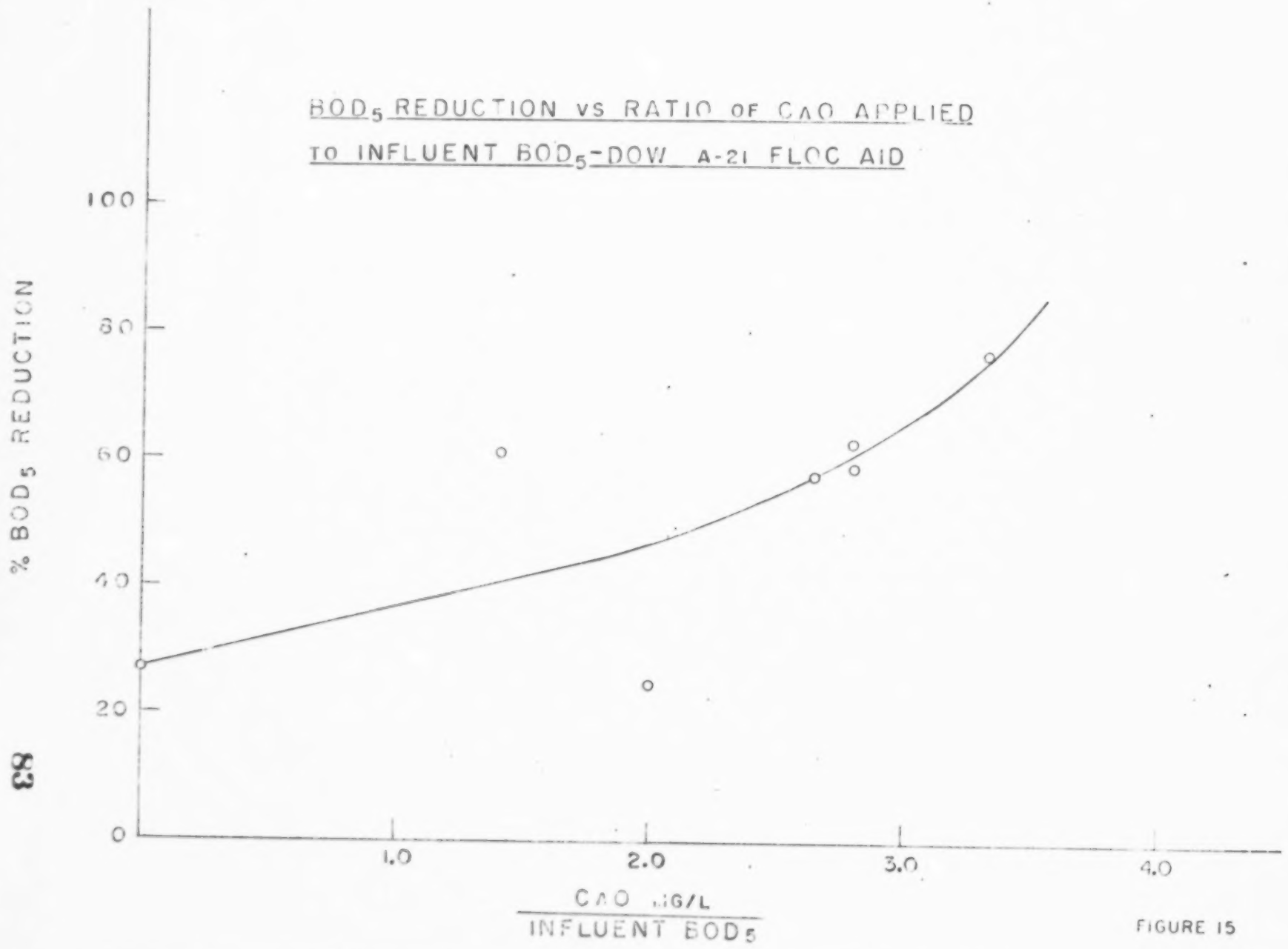

BOD5 REDUCTION VS RATIO OF CaO APPLIED
TO INFLUENT BOD5-DOW A-21 FLOC AID
% BOD5 REDUCTION
100
80
60
40
20
0
1.0
2.0
3.0
4.0
CaO MG/L
INFLUENT BOD5

FIGURE 15

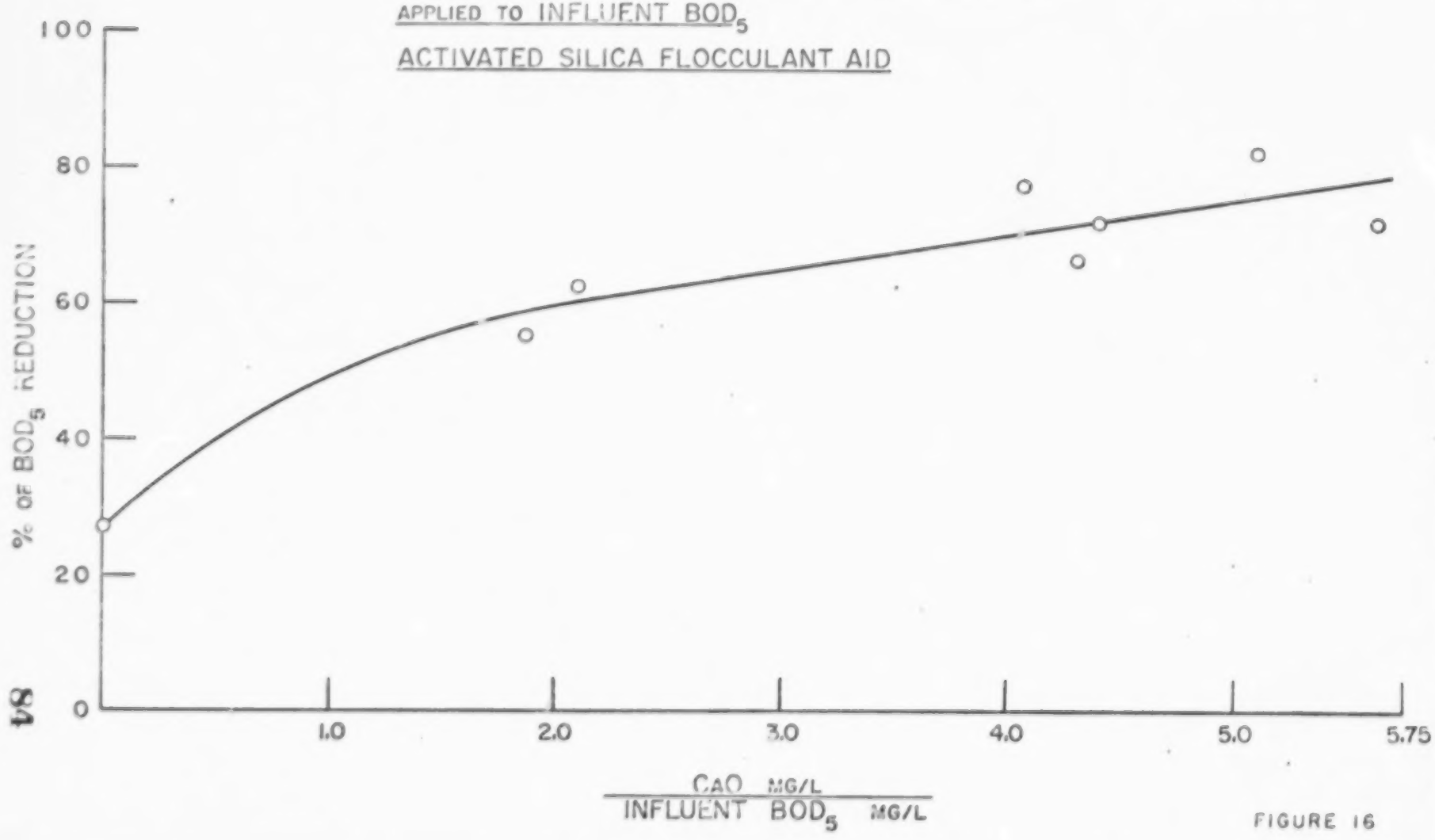

BOD5 REDUCTION IN SETTLING VS. RATIO OF CaO
APPLIED TO INFLUENT BOD5
ACTIVATED SILICA FLOCCULANT AID
% OF BOD5 REDUCTION
100
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
5.75
CaO MG/L
INFLUENT BOD5 MG/L

FIGURE 16

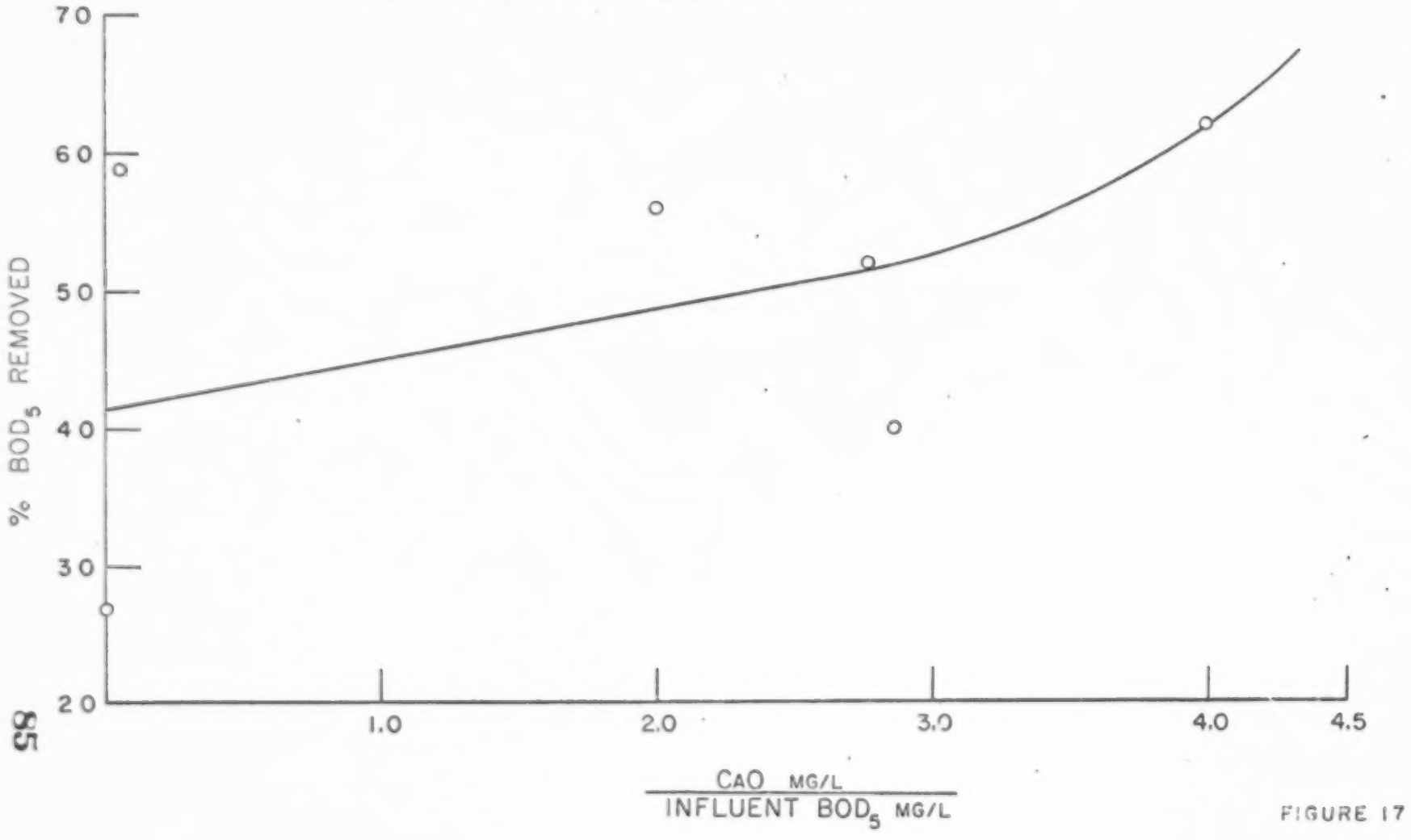

BOD5 REDUCTION IN SETTLING VS. RATIO OF
CaO APPLIED TO INFLUENT BOD5
FERRIC SULFATE FLOCCULANT AID
% BOD5 REMOVED
70
60
50
40
30
20
1.0
2.0
3.0
4.0
4.5
CaO MG/L
INFLUENT BOD5 MG/L

FIGURE 17

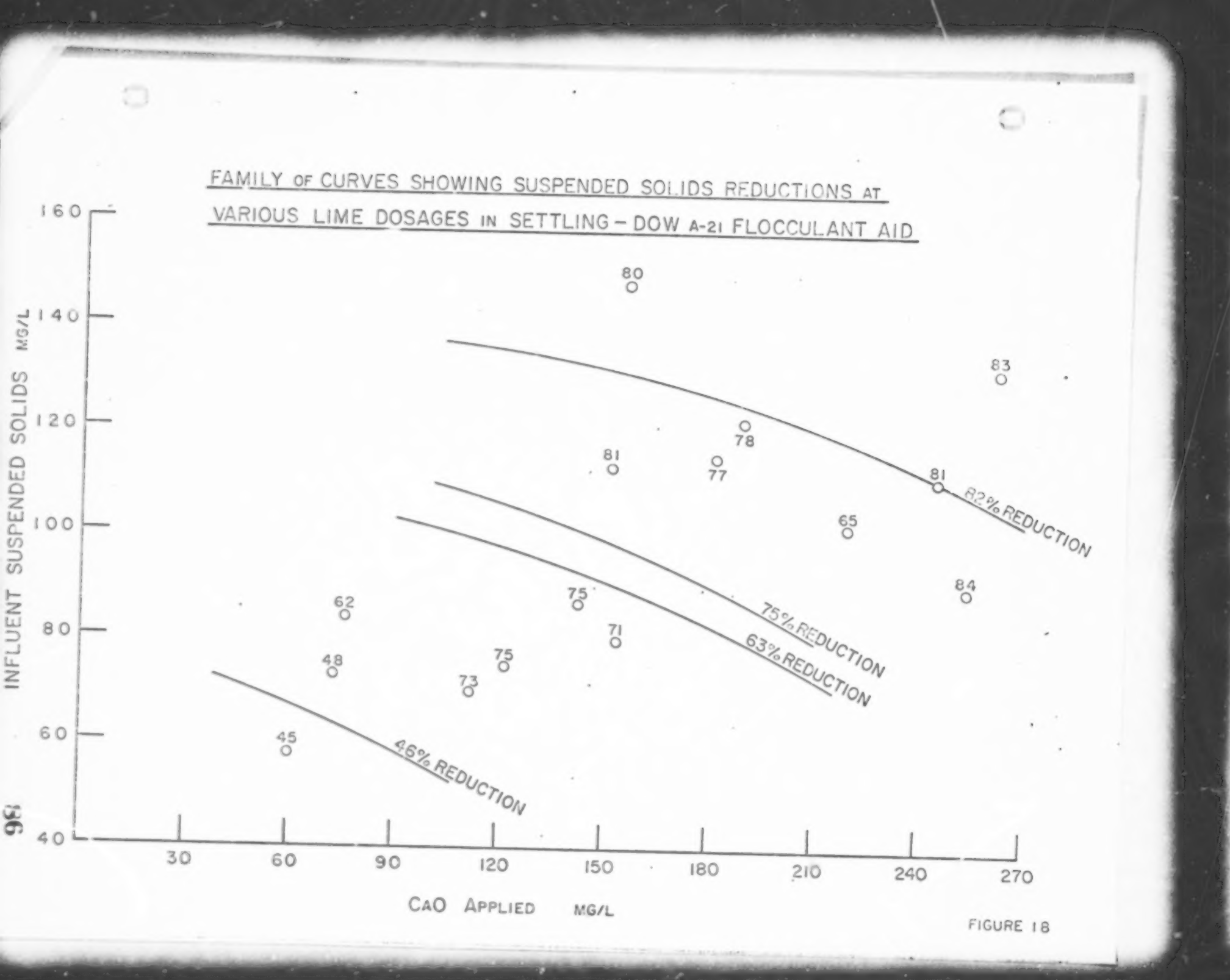

FAMILY OF CURVES SHOWING SUSPENDED SOLIDS REDUCTIONS AT
VARIOUS LIME DOSAGES IN SETTLING – DOW A-21 FLOCCULANT AID
INFLUENT SUSPENDED SOLIDS MG/L
160
140
120
100
80
60
40
30
60
90
120
150
180
210
240
270
CaO APPLIED MG/L
80
83
78
81
77
81
82% REDUCTION
65
84
62
75
75% REDUCTION
71
48
75
63% REDUCTION
73
45
46% REDUCTION

FIGURE 18

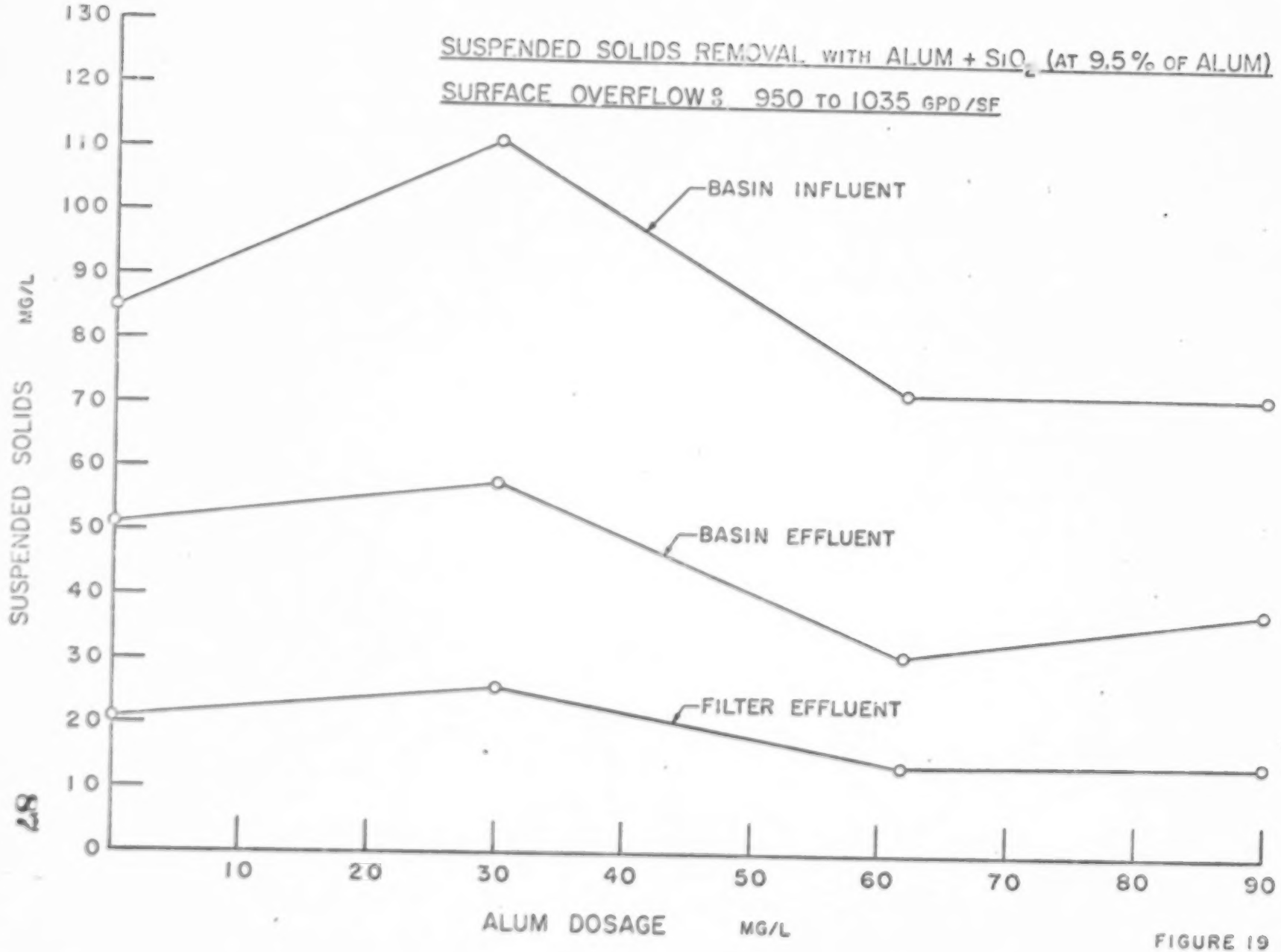

SUSPENDED SOLIDS REMOVAL WITH ALUM + SiO_2 (AT 9.5% OF ALUM)
SURFACE OVERFLOW @ 950 TO 1035 GPD/SF
BASIN INFLUENT
BASIN EFFLUENT
FILTER EFFLUENT
SUSPENDED SOLIDS MG/L
ALUM DOSAGE MG/L
0
10
20
30
40
50
60
70
80
90
100
110
120
130

FIGURE 19

SUSPENDED SOLIDS REDUCTION WITH ALUM & SiO_2 (AT 9.5% OF ALUM)

SURFACE OVERFLOW @ 655 TO 835 GPD/SF

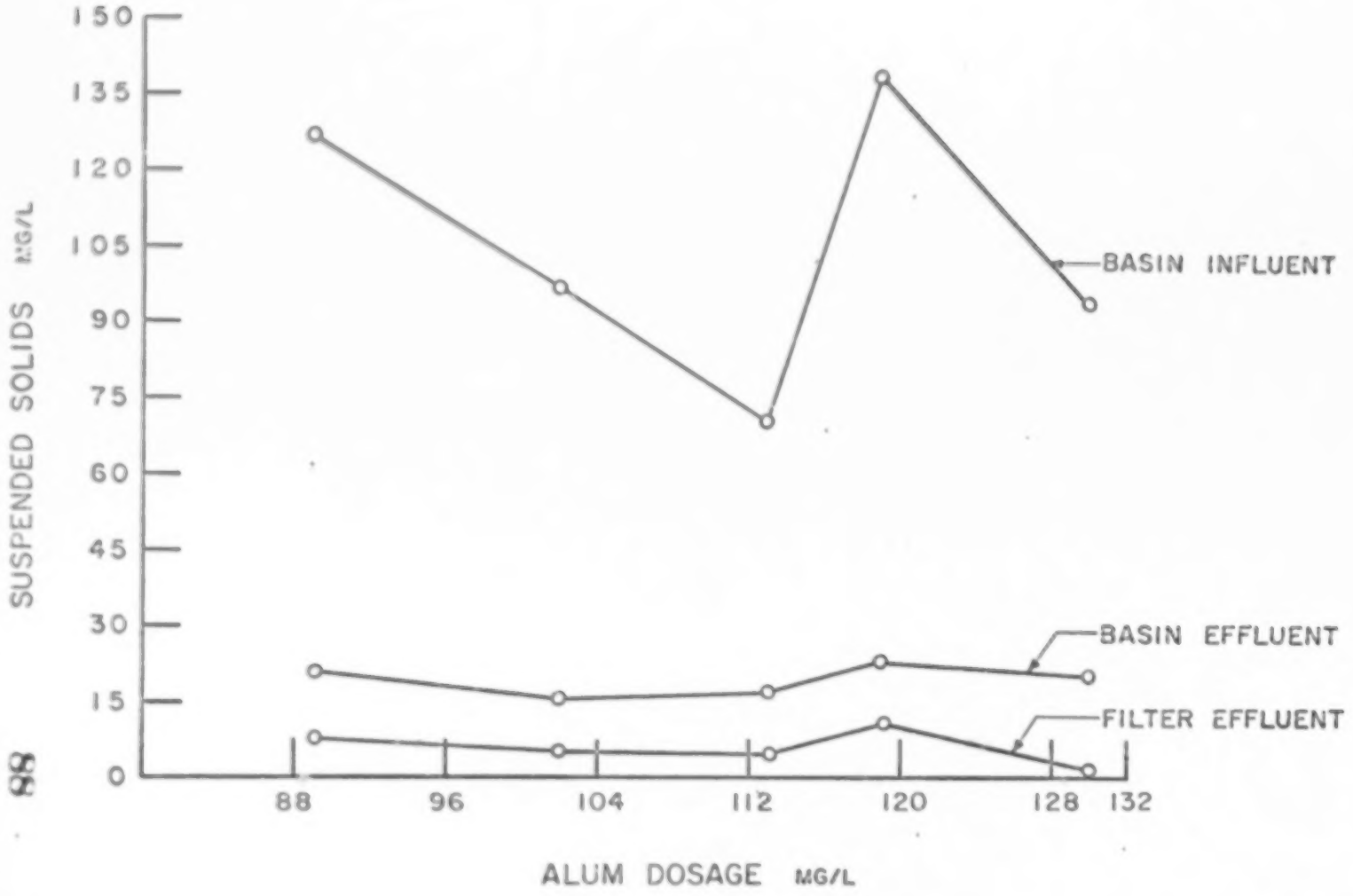


FIGURE 20

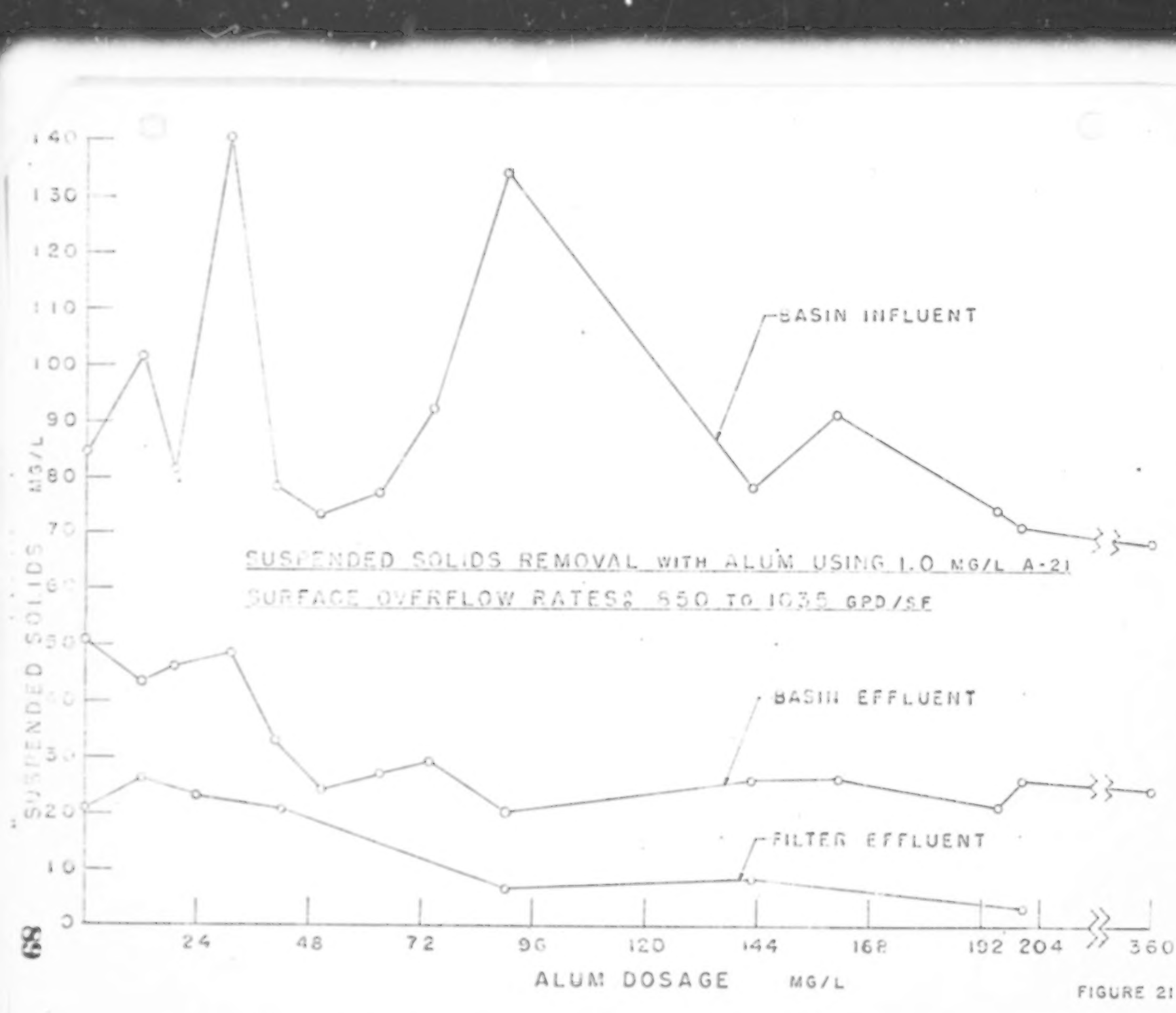

SUSPENDED SOLIDS MG/L
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
BASIN INFLUENT
SUSPENDED SOLIDS REMOVAL WITH ALUM USING 1.0 MG/L A-21
SURFACE OVERFLOW RATES: 550 TO 1035 GPD/SF
BASIN EFFLUENT
FILTER EFFLUENT
24
48
72
96
120
144
168
192
204
360
ALUM DOSAGE MG/L

FIGURE 21

SUSPENDED SOLIDS REDUCTIONS IN SETTLING AT VARIOUS ALUM TO SUSPENDED SOLIDS INFLUENT RATIOS -- ALUM + ACTIVATED SILICA

SURFACE OVERFLOW @ 950 TO 1035 GPD/SF

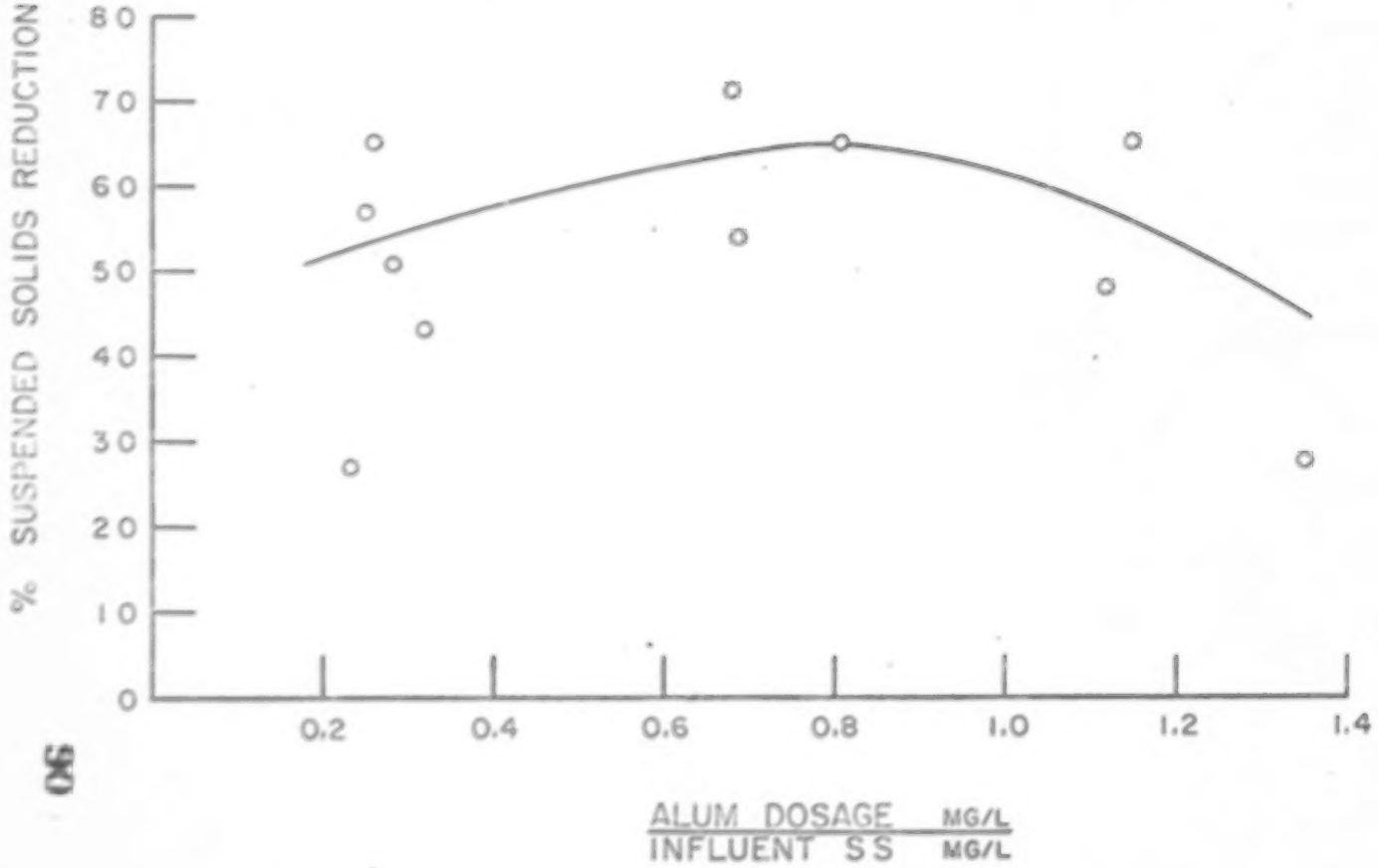


FIGURE 22

SUSPENDED SOLIDS REDUCTIONS IN SETTLING AT VARIOUS ALUM TO INFLUENT SUSPENDED SOLIDS RATIOS - ACTIVATED SILICA FLOCCULANT AID

SURFACE OVERFLOW @ 655 TO 835 GPD/SF

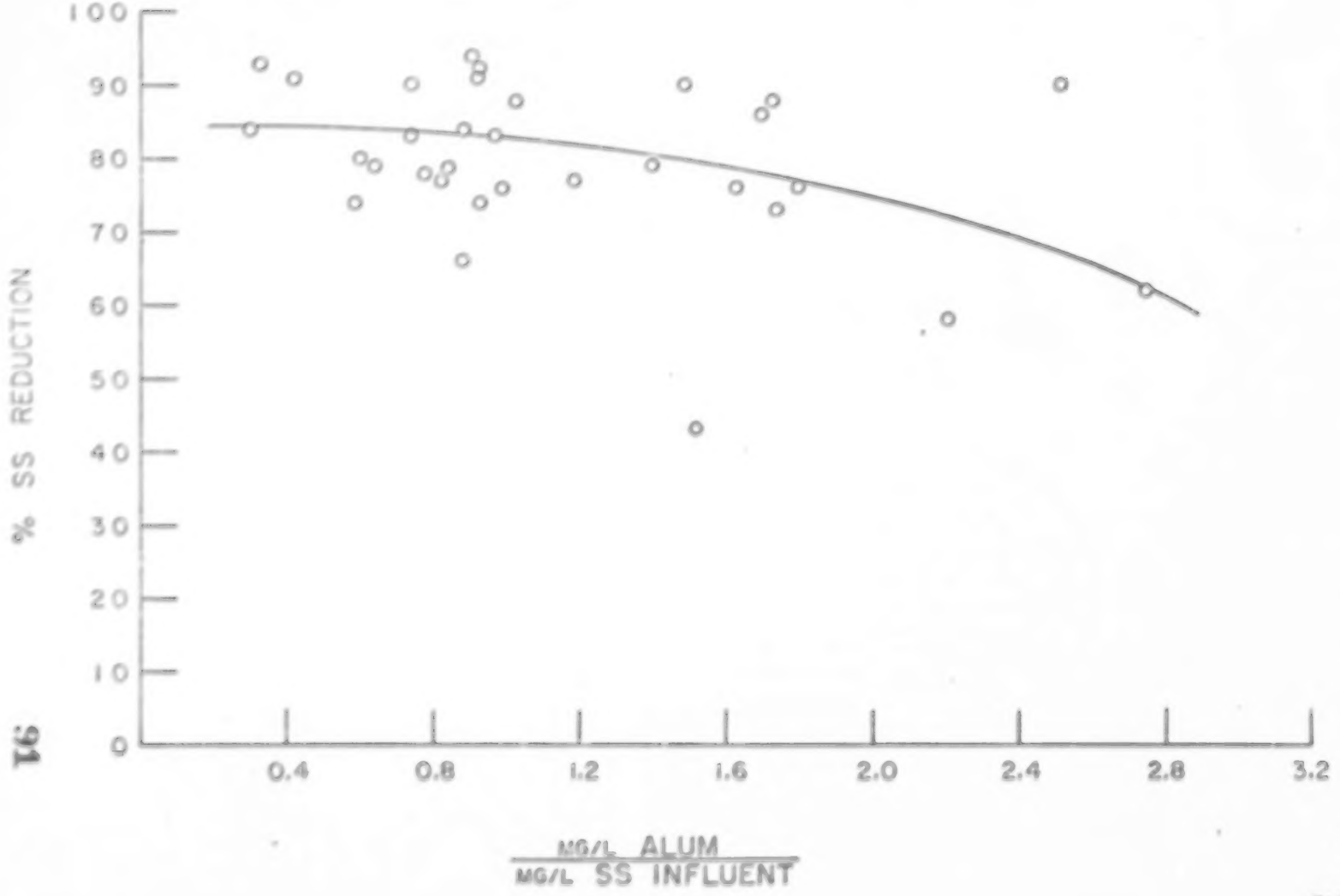


FIGURE 23

SUSPENDED SOLIDS REDUCTION VS RATIO OF ALUM TO INFLUENT SUSPENDED SOLIDS USING DOW A-21 FLOCCULANT AID

SURFACE OVERFLOW: 850 TO 1035 GPD/SF

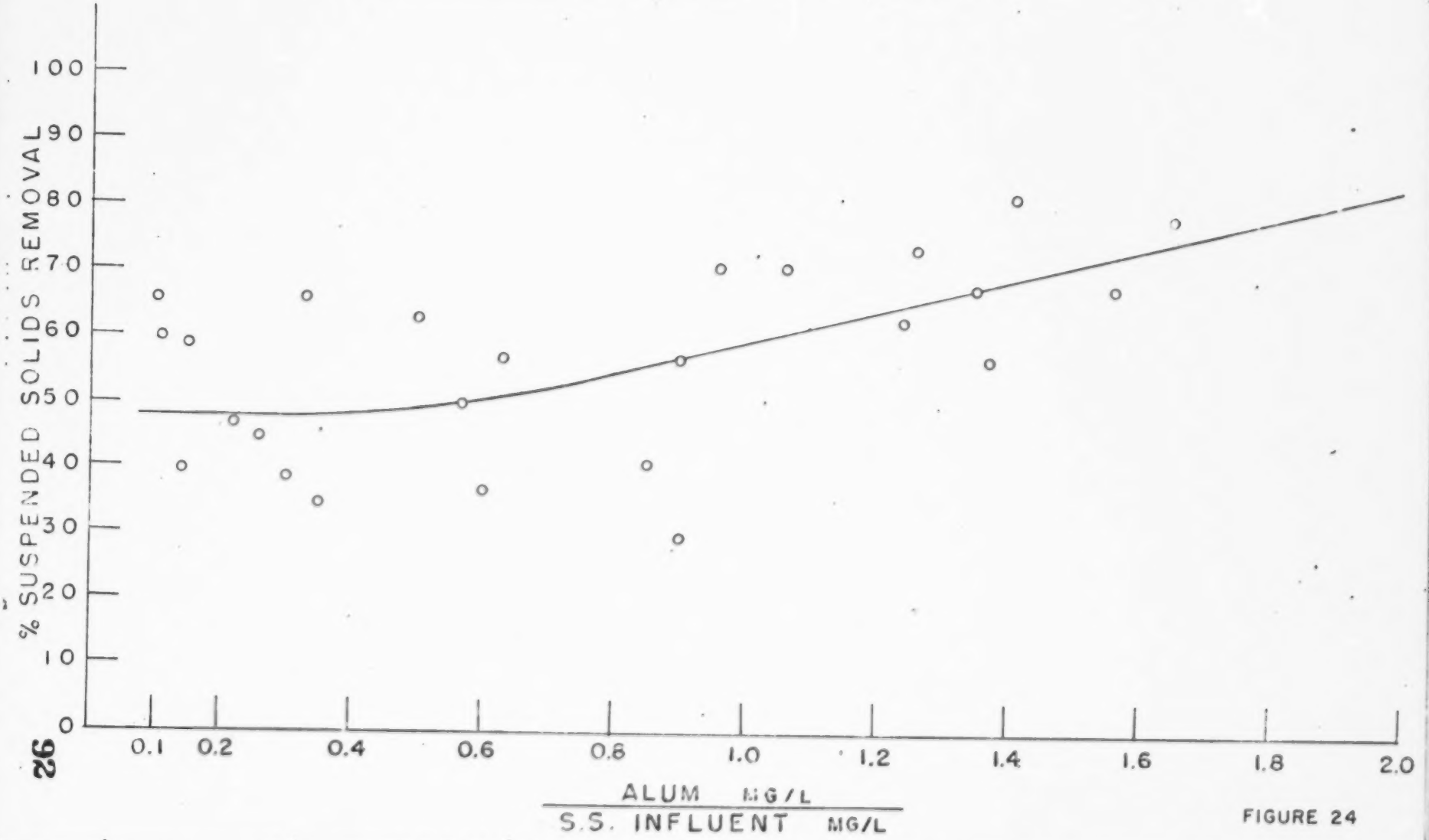


FIGURE 24

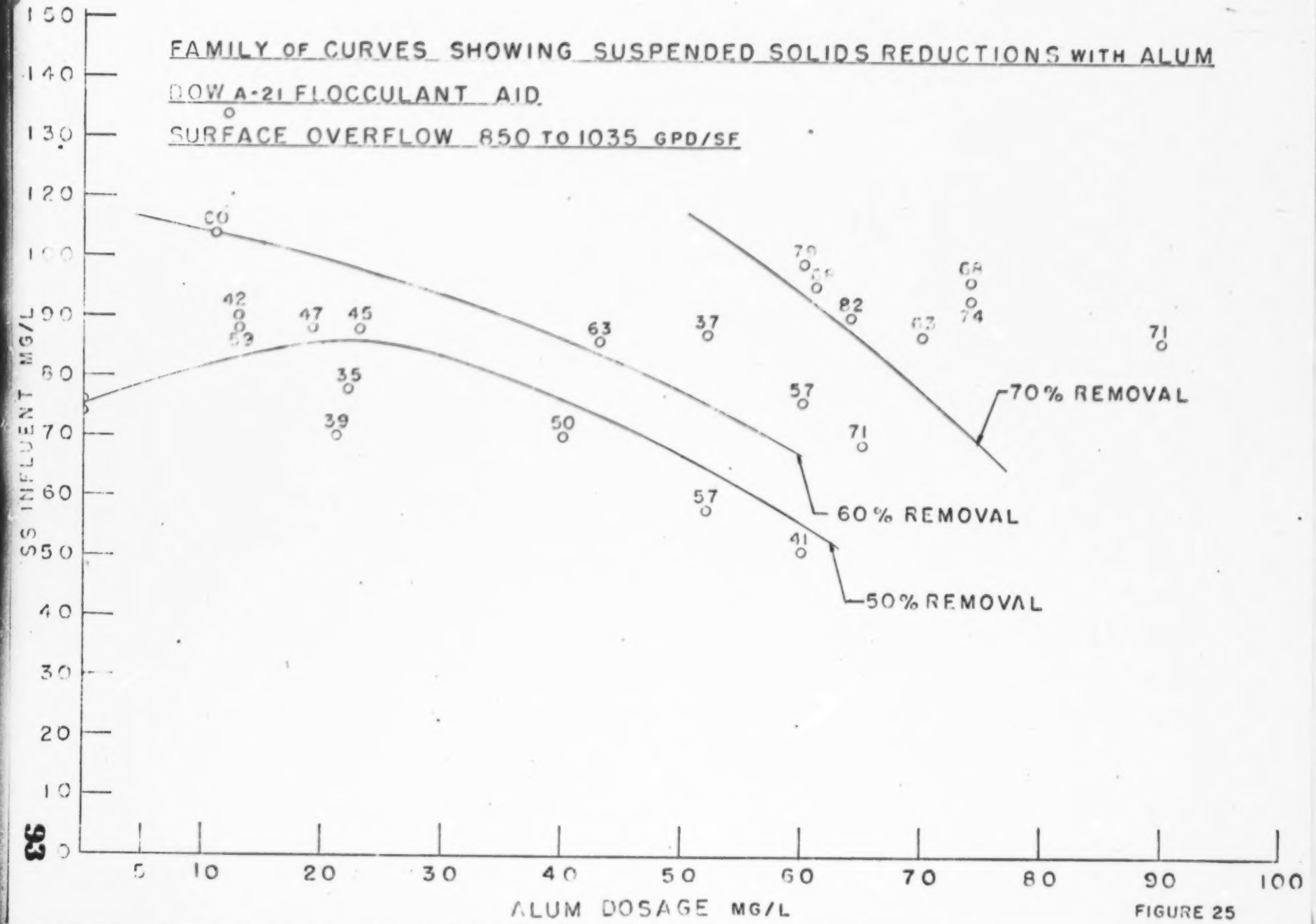

FAMILY OF CURVES SHOWING SUSPENDED SOLIDS REDUCTIONS WITH ALUM
DOW A-21 FLOCCULANT AID
SURFACE OVERFLOW 850 TO 1035 GPD/SF
SS INFLUENT MG/L
ALUM DOSAGE MG/L
70% REMOVAL
60% REMOVAL
50% REMOVAL
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
5
10
20
30
40
50
60
70
80
90
100
60
42
53
47
45
35
39
63
50
37
57
41
79
82
63
68
74
71

FIGURE 25

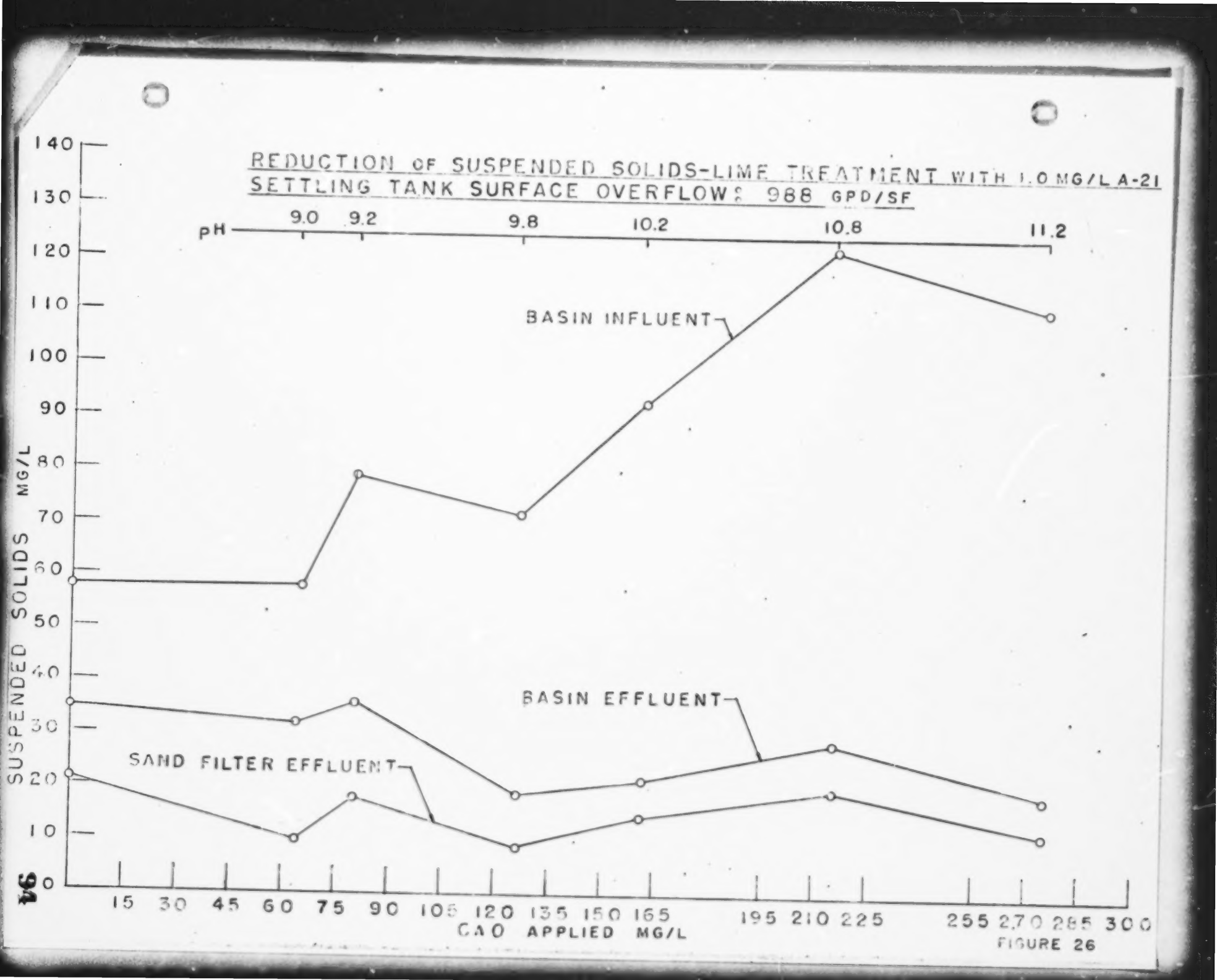

REDUCTION OF SUSPENDED SOLIDS-LIME TREATMENT WITH 1.0 MG/L A-21
SETTLING TANK SURFACE OVERFLOW: 988 GPD/SF
pH
9.0
9.2
9.8
10.2
10.8
11.2
BASIN INFLUENT
BASIN EFFLUENT
SAND FILTER EFFLUENT
SUSPENDED SOLIDS MG/L
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
15 30 45 60 75 90 105 120 135 150 165 195 210 225 255 270 285 300
CAO APPLIED MG/L

FIGURE 26

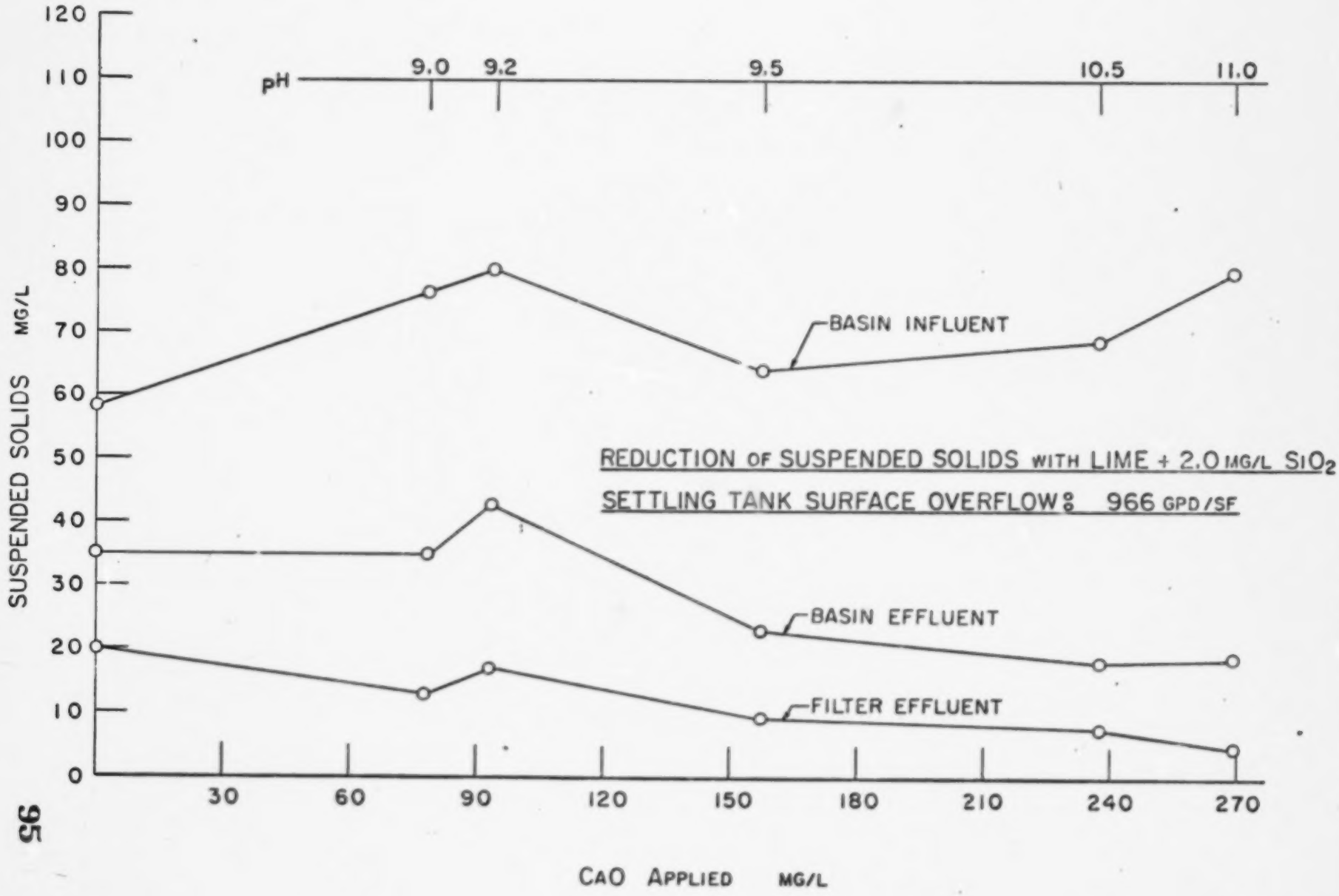

pH
9.0
9.2
9.5
10.5
11.0
SUSPENDED SOLIDS MG/L
120
110
100
90
80
70
60
50
40
30
20
10
0
BASIN INFLUENT
REDUCTION OF SUSPENDED SOLIDS WITH LIME + 2.0 MG/L SiO_2
SETTLING TANK SURFACE OVERFLOW @ 966 GPD/SF
BASIN EFFLUENT
FILTER EFFLUENT
30
60
90
120
150
180
210
240
270
CaO APPLIED MG/L

FIGURE 27

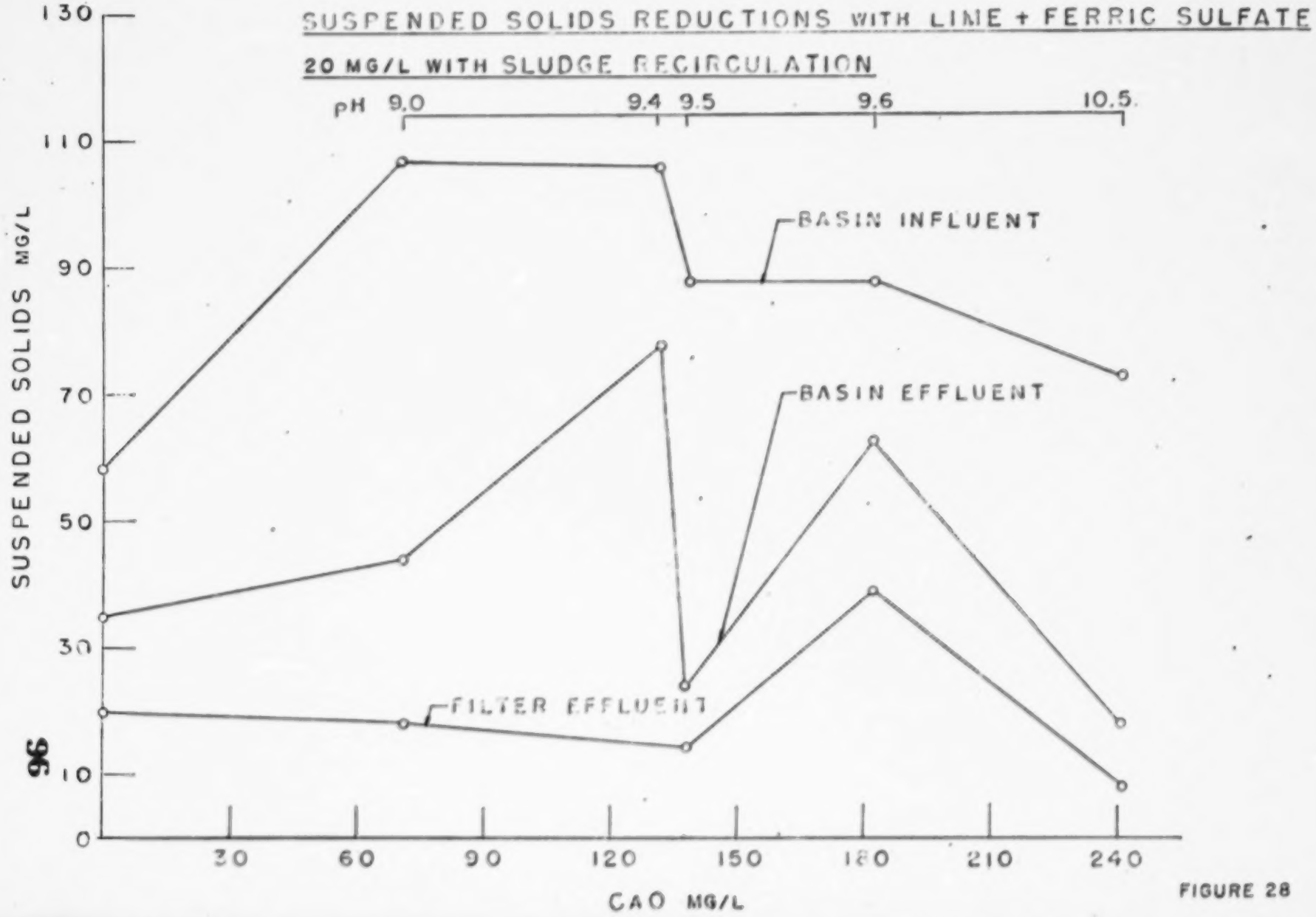

SUSPENDED SOLIDS REDUCTIONS WITH LIME + FERRIC SULFATE
20 MG/L WITH SLUDGE RECIRCULATION
pH 9.0 9.4 9.5 9.6 10.5
SUSPENDED SOLIDS MG/L
130
110
90
70
50
30
10
0
BASIN INFLUENT
BASIN EFFLUENT
FILTER EFFLUENT
30 60 90 120 150 180 210 240
CAO MG/L

FIGURE 28

SUSPENDED SOLIDS REDUCTION VS. RATIO OF CaO APPLIED TO INFLUENT SUSPENDED SOLIDS

DOW A-21 FLOCCULANT AID

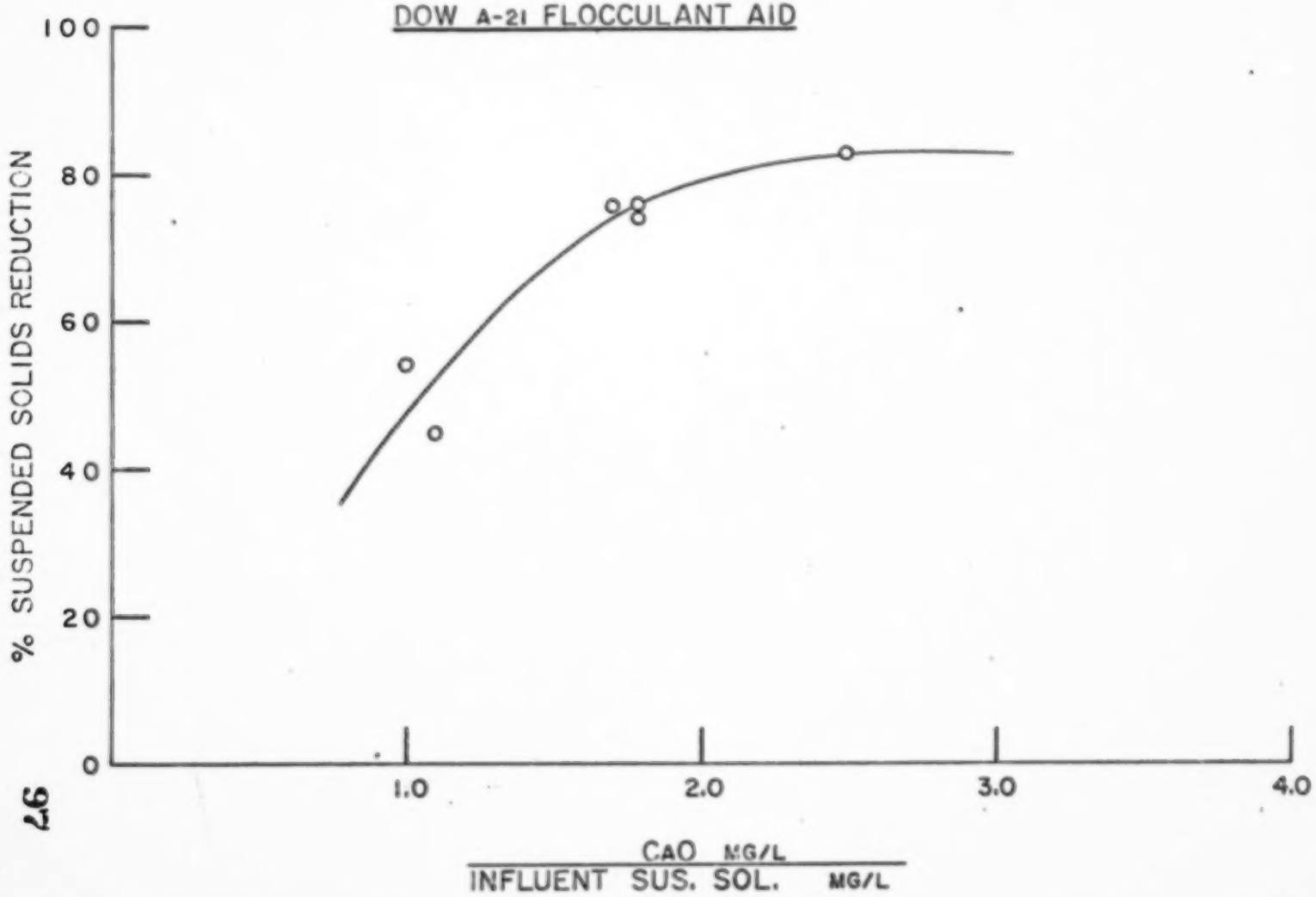


FIGURE 29

SUSPENDED SOLIDS REDUCTION IN SETTLING VS. RATIO OF CaO APPLIED TO INFLUENT SUSPENDED SOLIDS-ACTIVATED SILICA FLOCCULANT AID

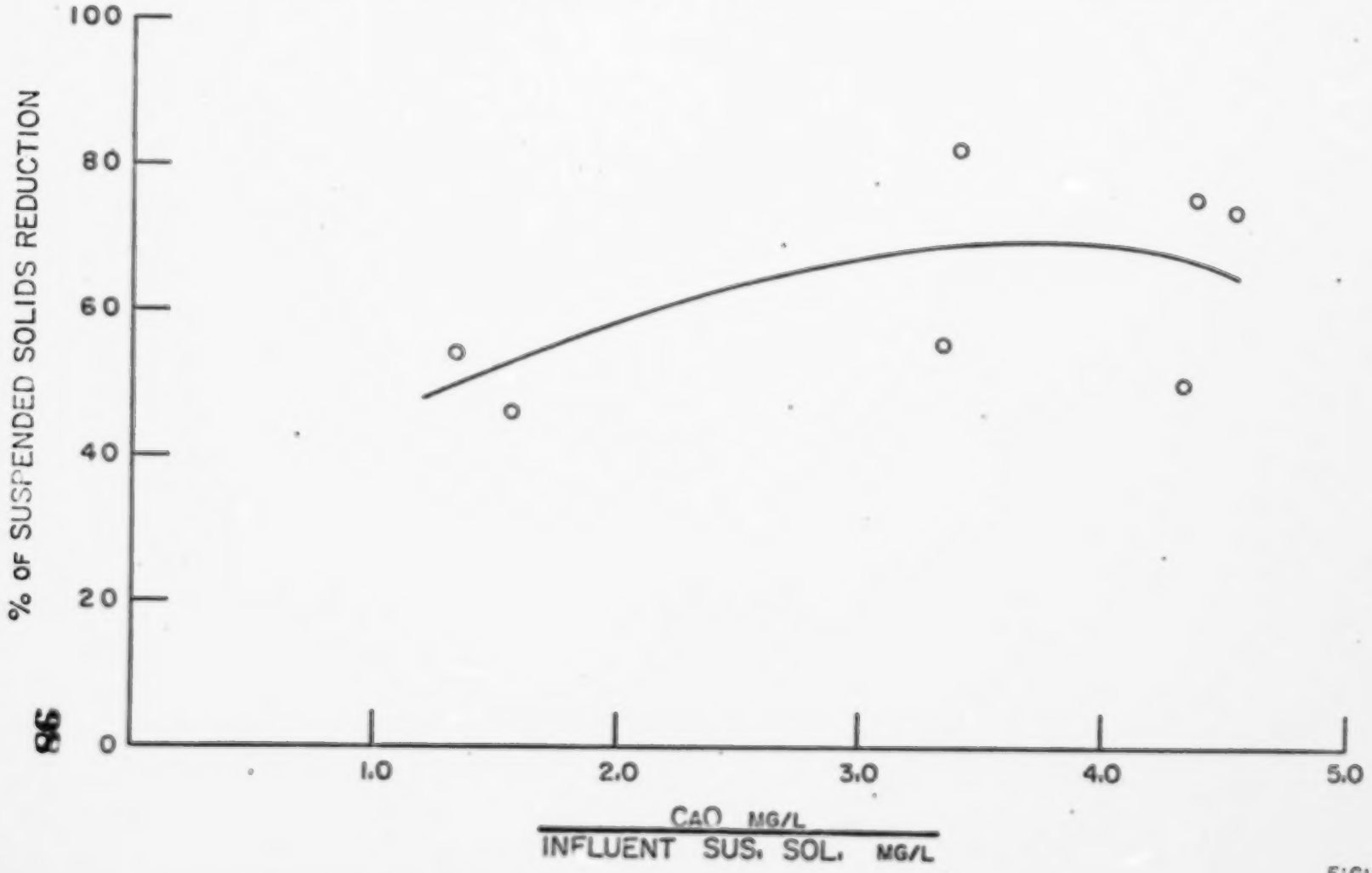


FIGURE 30

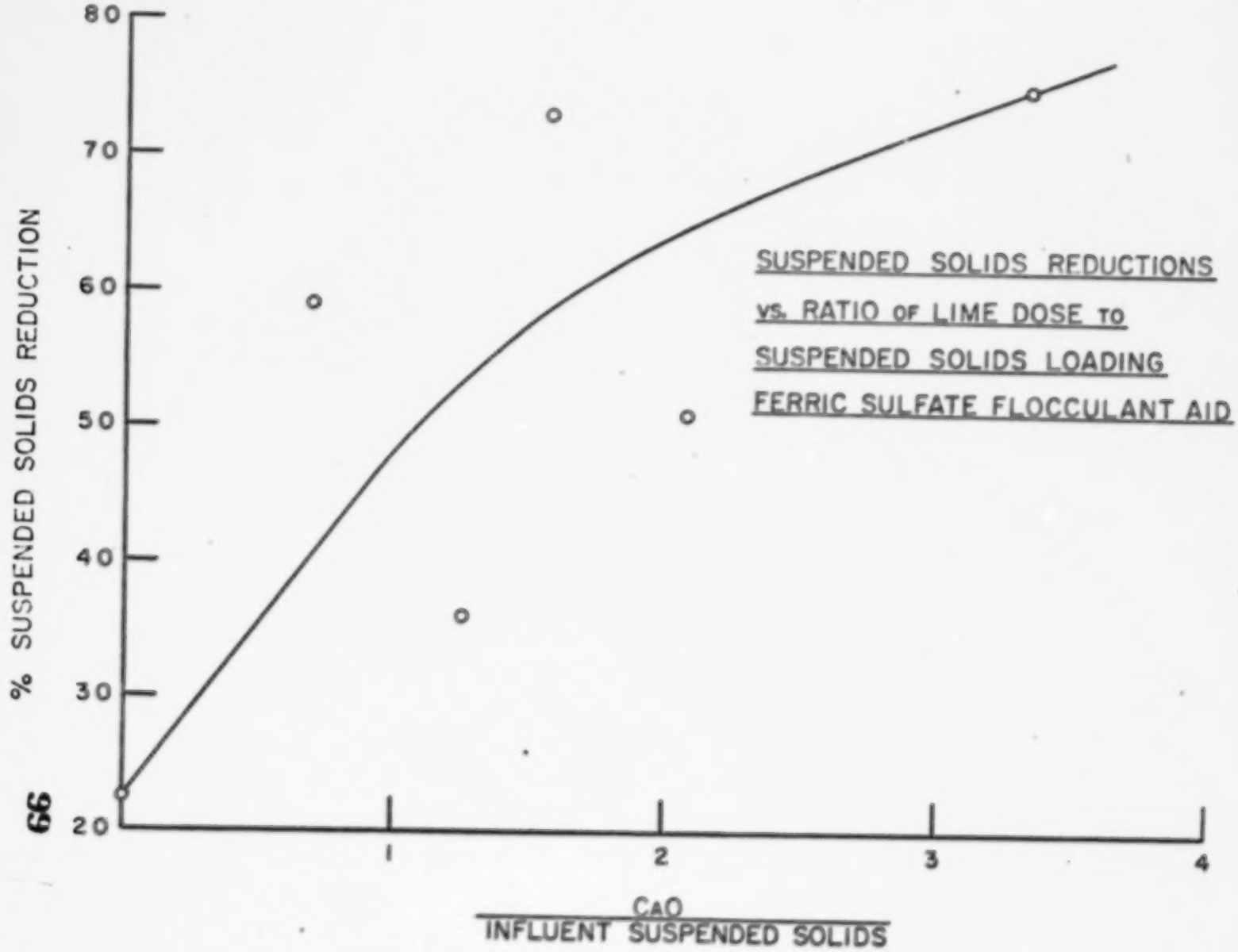

80
70
60
50
40
30
20
% SUSPENDED SOLIDS REDUCTION
1
2
3
4
CaO
INFLUENT SUSPENDED SOLIDS
SUSPENDED SOLIDS REDUCTIONS
VS. RATIO OF LIME DOSE TO
SUSPENDED SOLIDS LOADING
FERRIC SULFATE FLOCCULANT AID

FIGURE 31

PHOSPHATE REMOVAL WITH ALUM TREATMENT

USING SiO_2 (AT 9.5% OF ALUM) FLOCCULANT AID

SURFACE OVERFLOW @ 950 TO 1035 GPD/SF

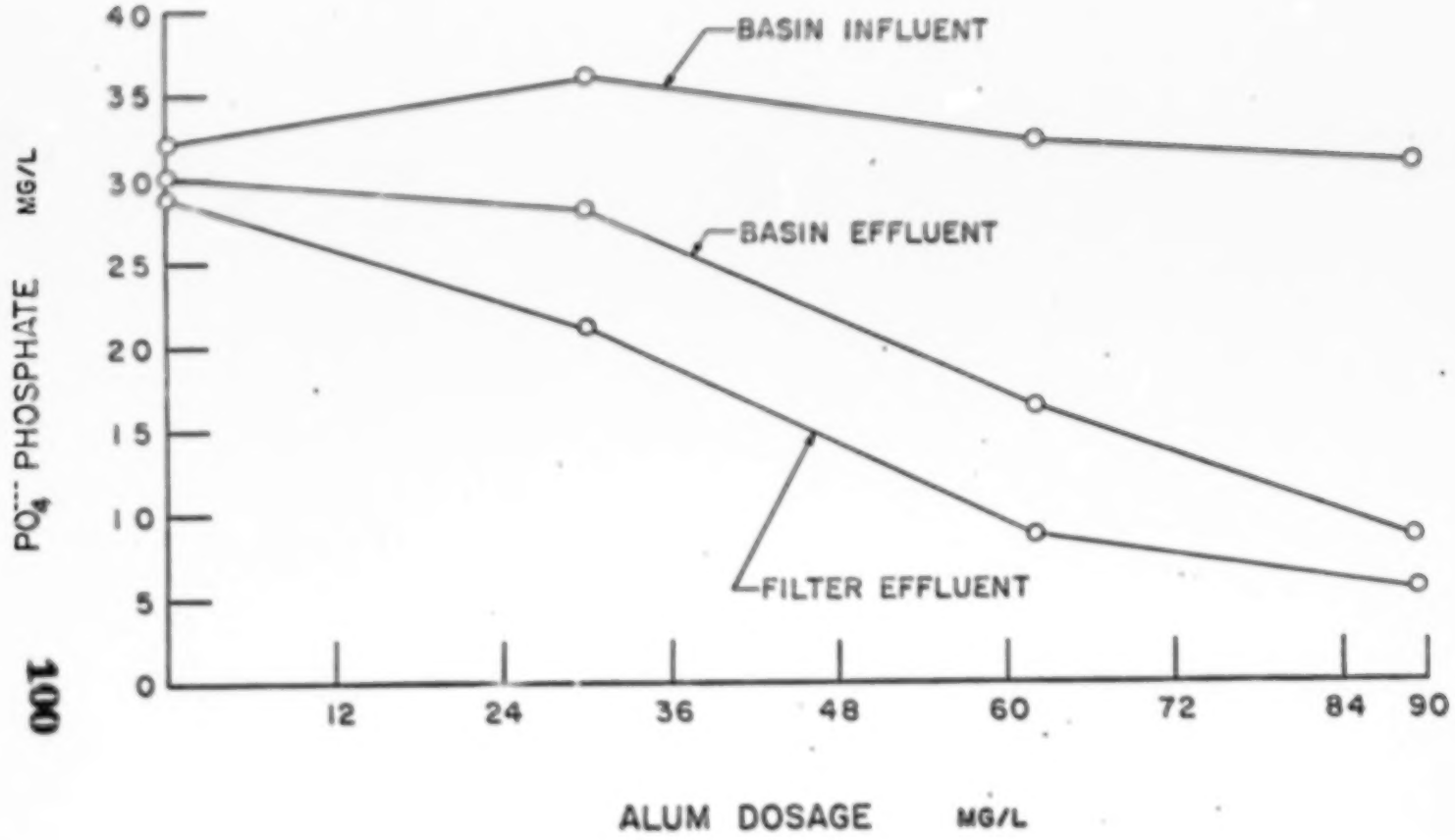


FIGURE 32

PHOSPHATE REMOVAL WITH ALUM + SiO_2 (AT 9.5% OF ALUM)
SURFACE OVERFLOW @ 655 TO 835 GPD/SF

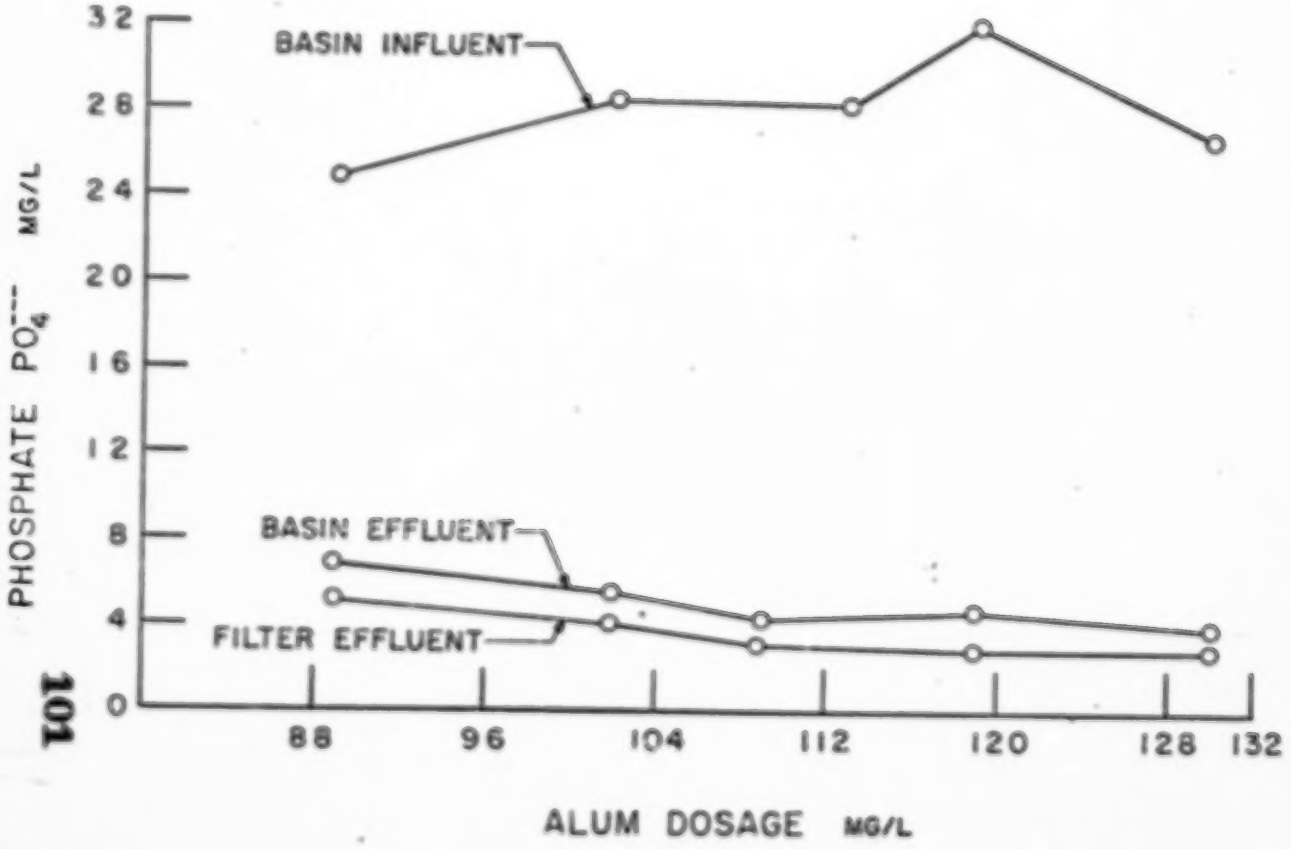


FIGURE 33

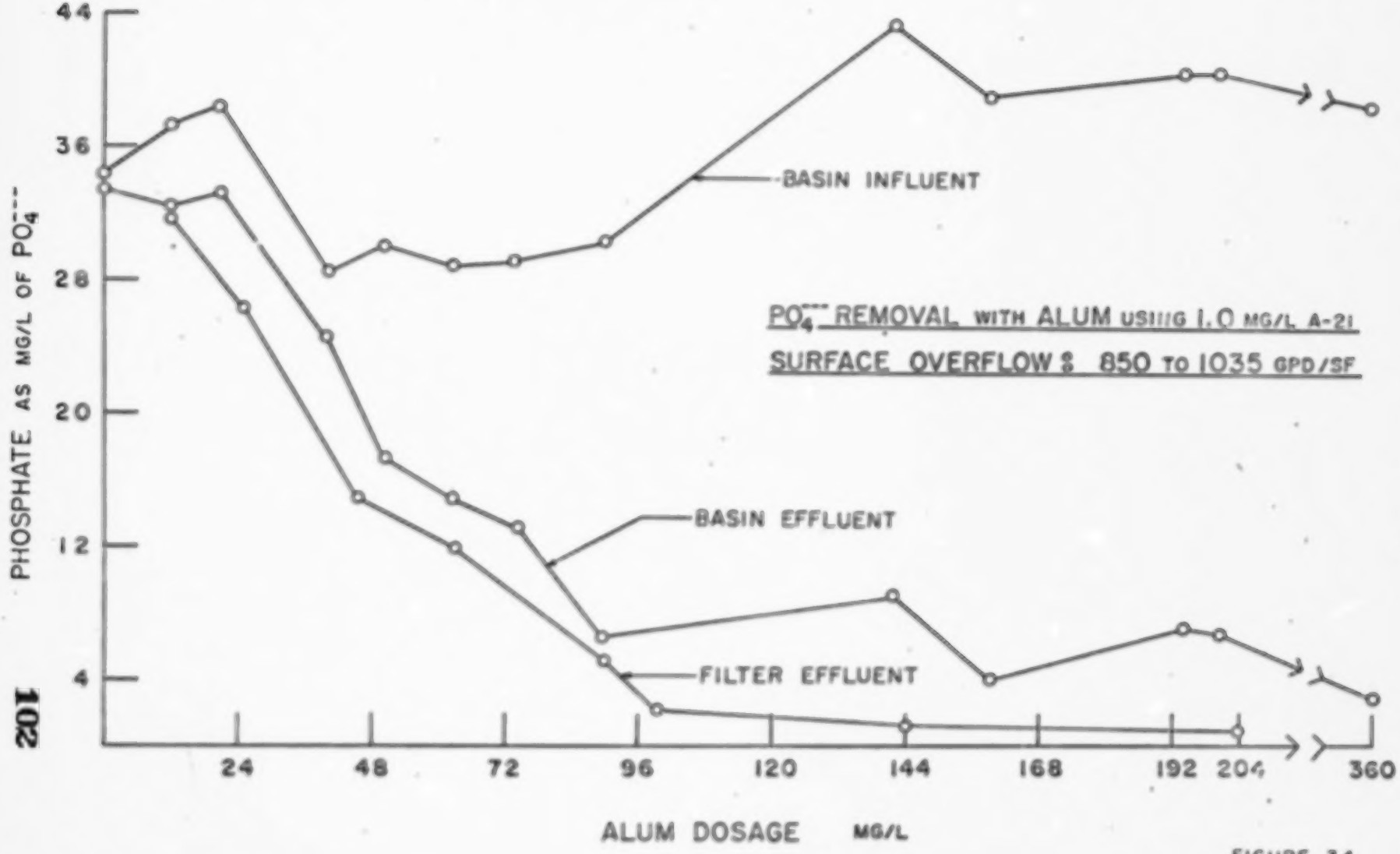

44
36
28
20
12
4
PHOSPHATE AS MG/L OF PO_4^{---}
BASIN INFLUENT
PO_4^{---} REMOVAL WITH ALUM USING 1.0 MG/L A-21
SURFACE OVERFLOW @ 850 TO 1035 GPD/SF
BASIN EFFLUENT
FILTER EFFLUENT
24
48
72
96
120
144
168
192
204
360
ALUM DOSAGE MG/L

FIGURE 34

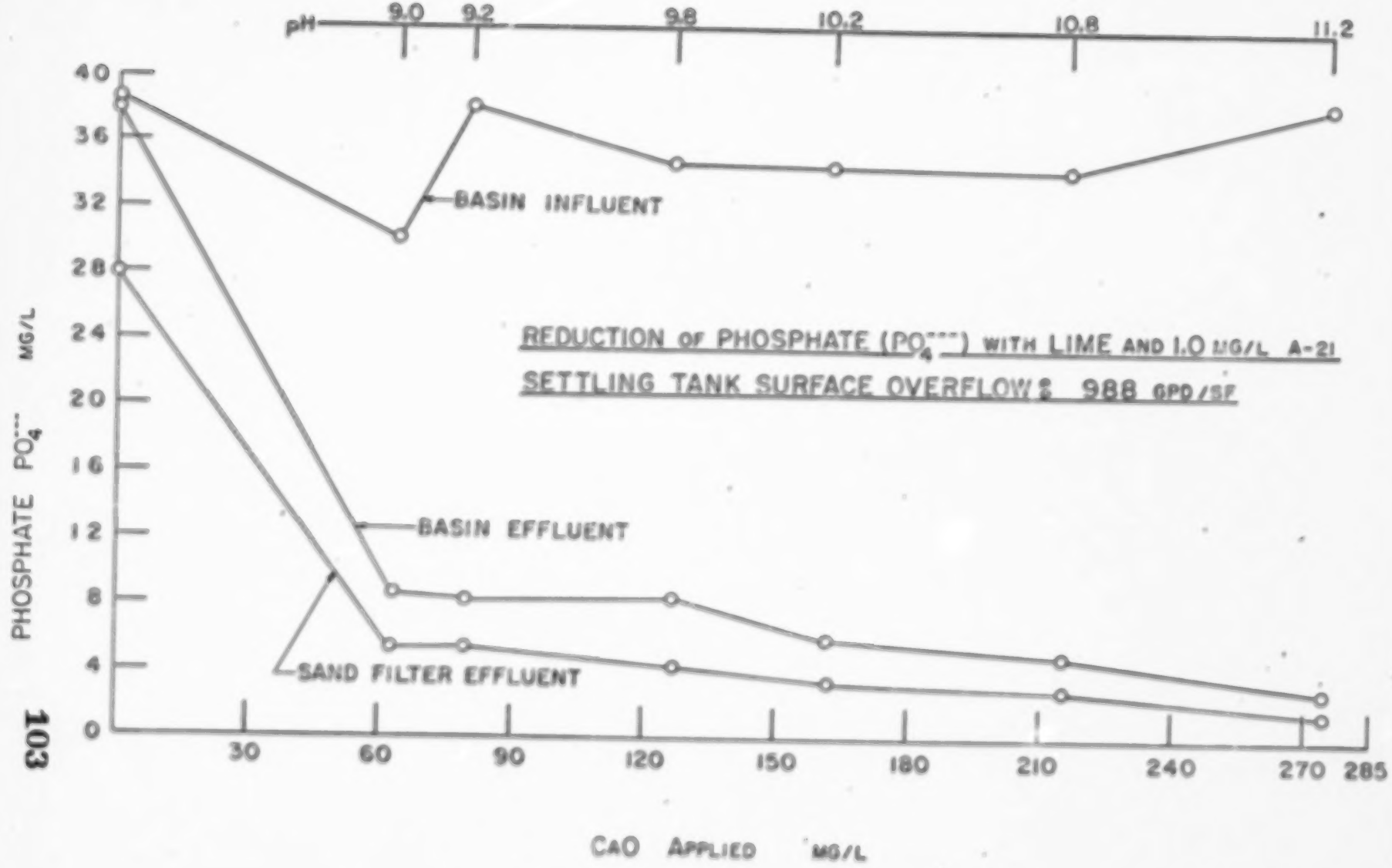
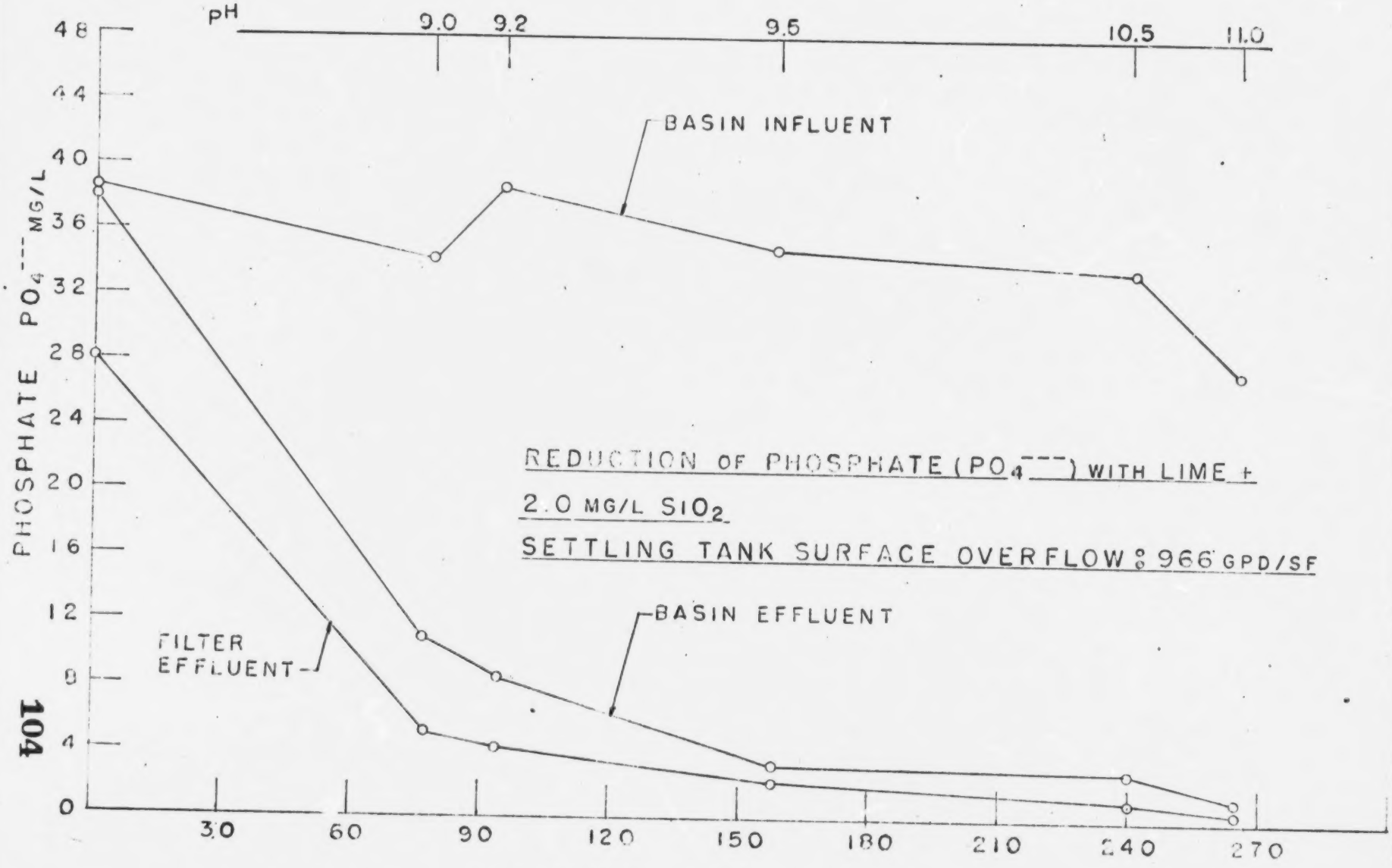

pH
9.0
9.2
9.8
10.2
10.8
11.2
40
36
32
28
24
20
16
12
8
4
0
PHOSPHATE PO_4^{---} MG/L
BASIN INFLUENT
BASIN EFFLUENT
SAND FILTER EFFLUENT
REDUCTION OF PHOSPHATE (PO_4^{---}) WITH LIME AND 1.0 MG/L A-21
SETTLING TANK SURFACE OVERFLOW @ 988 GPD/SF
30
60
90
120
150
180
210
240
270
285
CaO APPLIED MG/L

FIGURE 35



REDUCTION OF PHOSPHATE (PO_4^{---}) WITH LIME + 2.0 MG/L SiO_2

SETTLING TANK SURFACE OVERFLOW @ 966 GPD/SF

FIGURE 36

PHOSPHATE REDUCTION WITH LIME + FERRIC SULFATE (20 MG/L) WITH SLUDGE RECIRCULATION

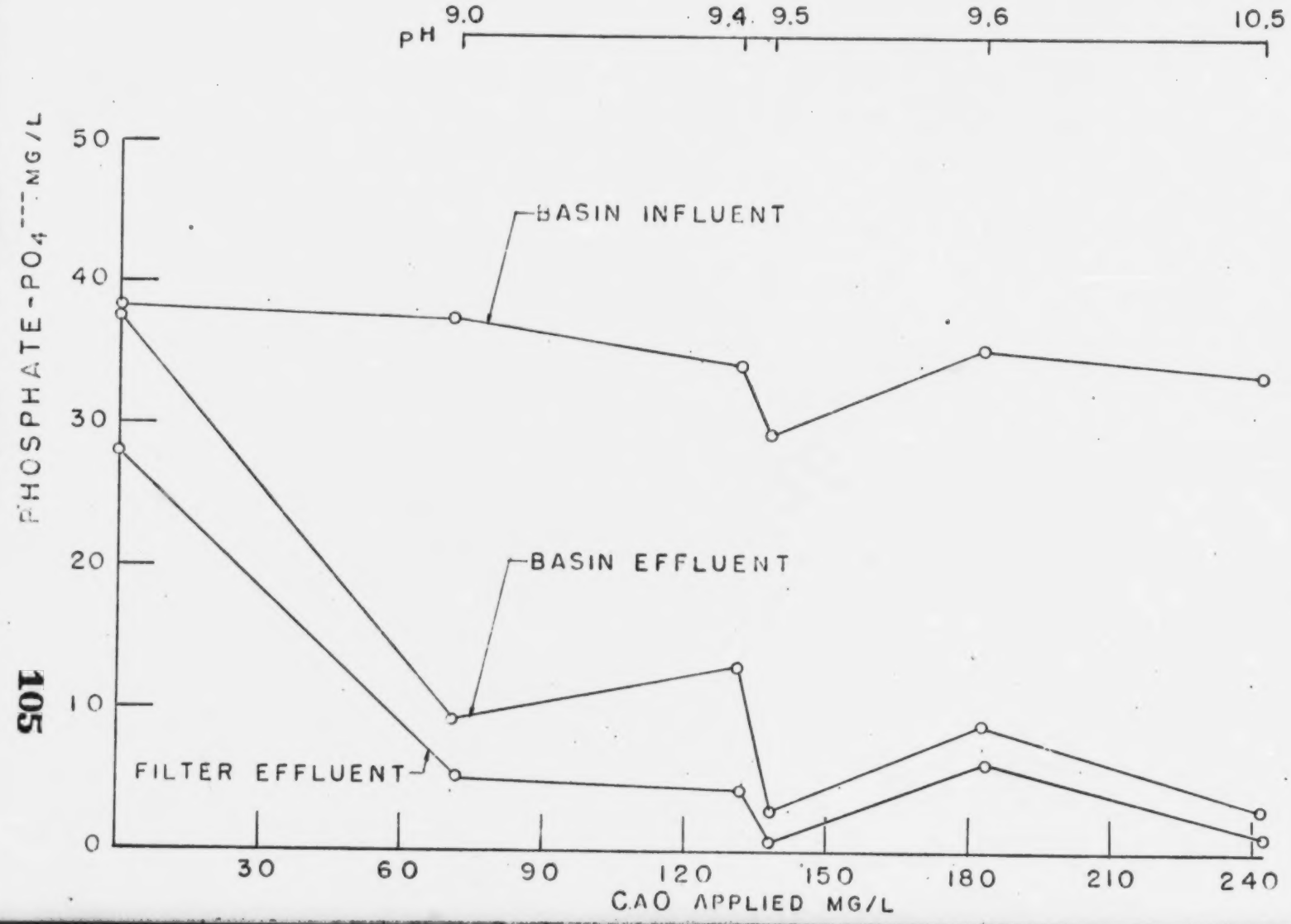


FIGURE 37

RATIO OF PHOSPHATE REMOVED TO ALUM APPLIED VS PHOSPHATE RESIDUAL-ACTIVATED SILICA FLOCCULANT AID

SURFACE OVERFLOW 950 TO 1035 GPD/SF

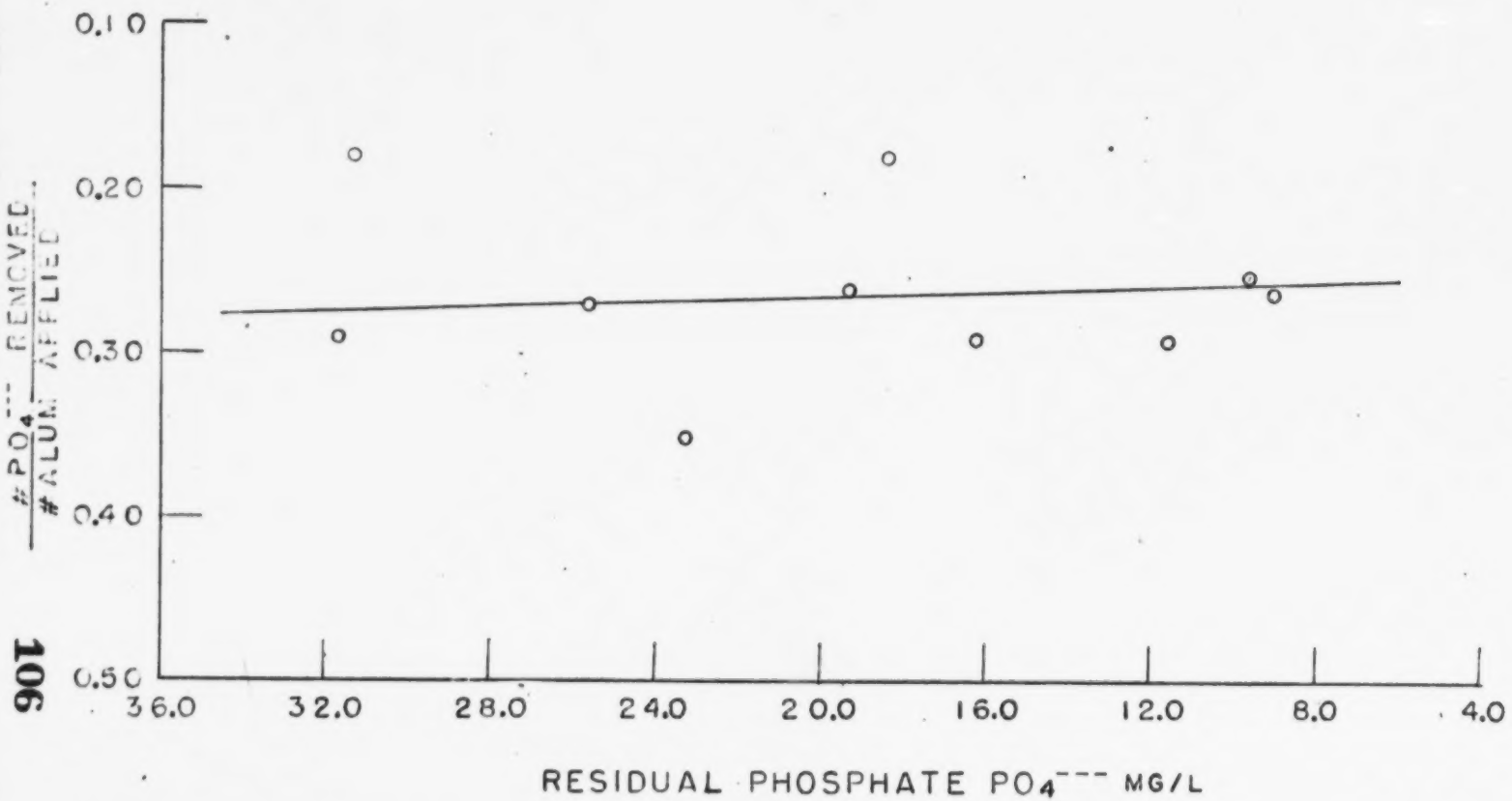


FIGURE 38

RATIO OF PHOSPHATE REMOVED TO ALUM APPLIED VS. PHOSPHATE RESIDUAL

ACTIVATED SILICA FLOCCULANT AID

SURFACE OVERFLOW @ 655 TO 835 GPD/SF

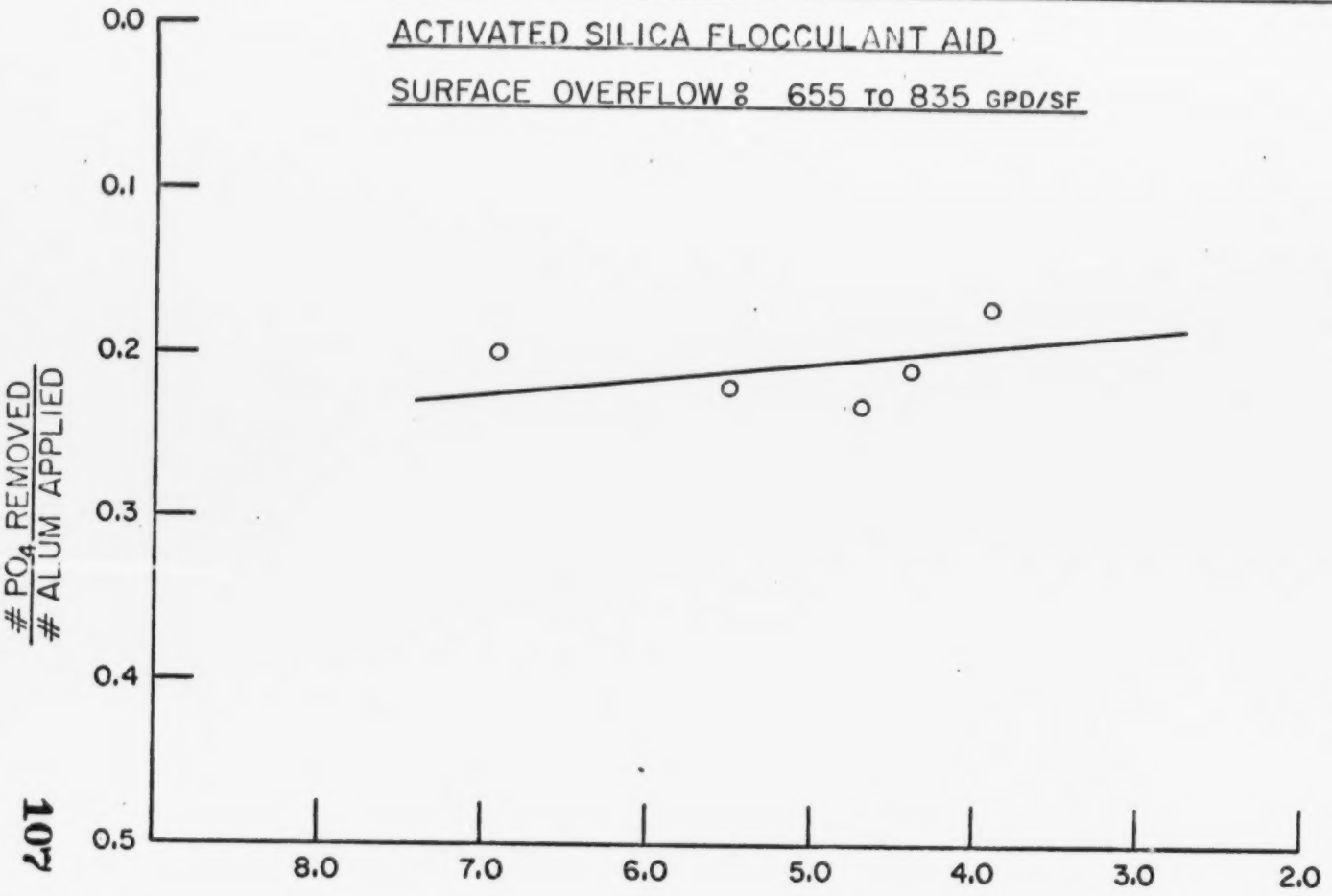


FIGURE 39

RATIO OF PHOSPHATE REMOVED TO ALUM APPLIED VS PHOSPHATE RESIDUAL IN EFFLUENT

DOW A-21 FLOCCULANT AID

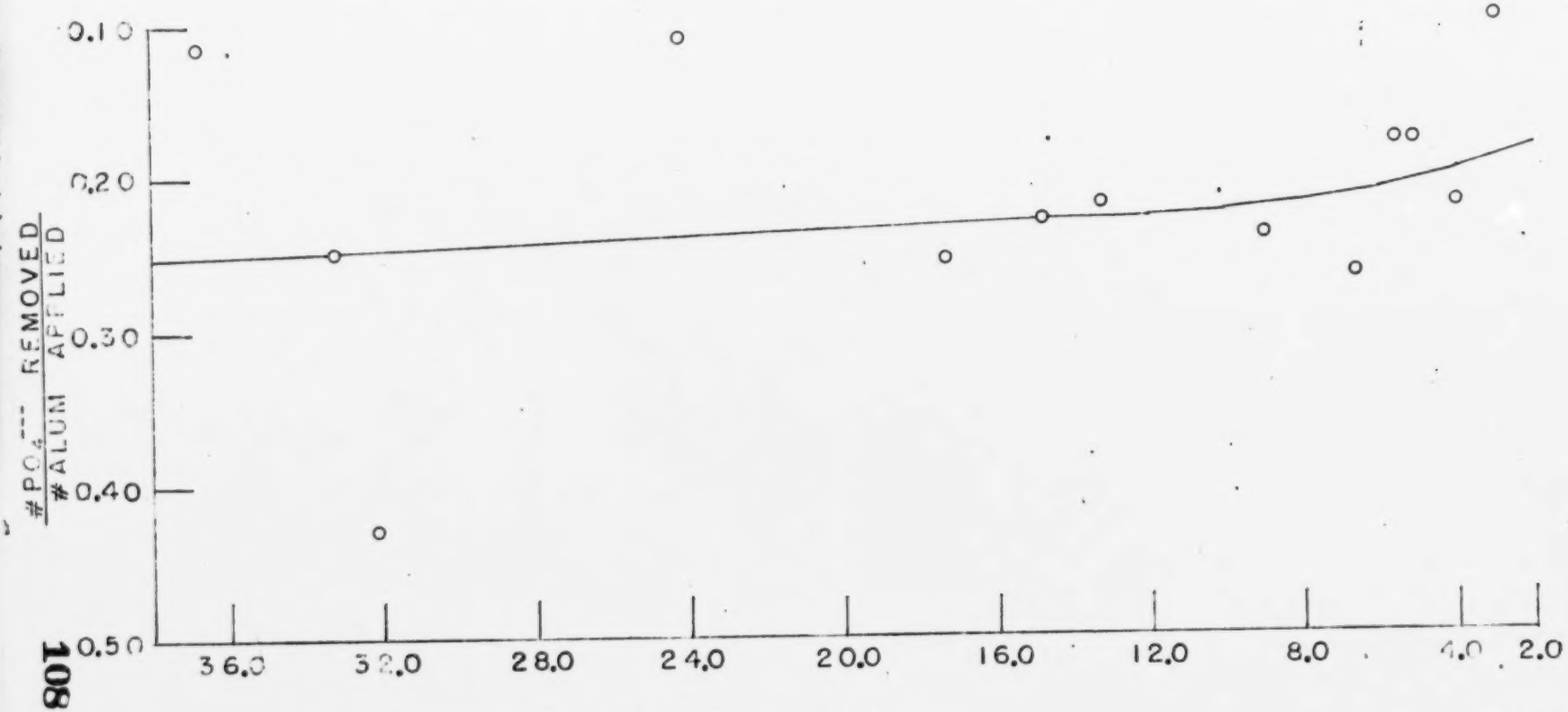


FIGURE 40

PHOSPHATE RESIDUAL vs. RATIO OF PHOSPHATE REMOVED TO CaO APPLIED

DOW A-21 FLOCCULANT AID

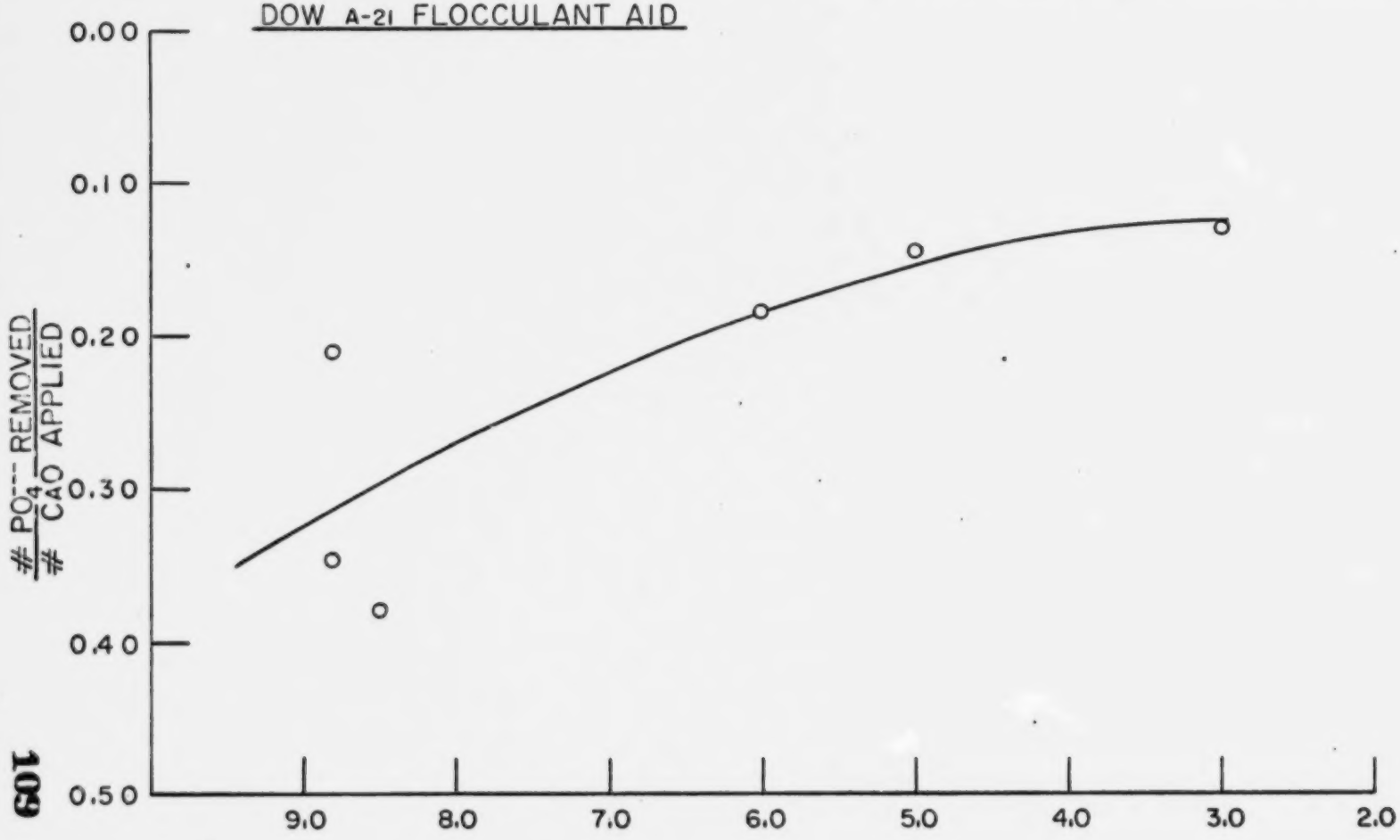


FIGURE 41

PHOSPHATE RESIDUAL VS RATIO OF PO_4^{---} REMOVED TO CAO APPLIED
ACTIVATED SILICA FLOCCULANT AID

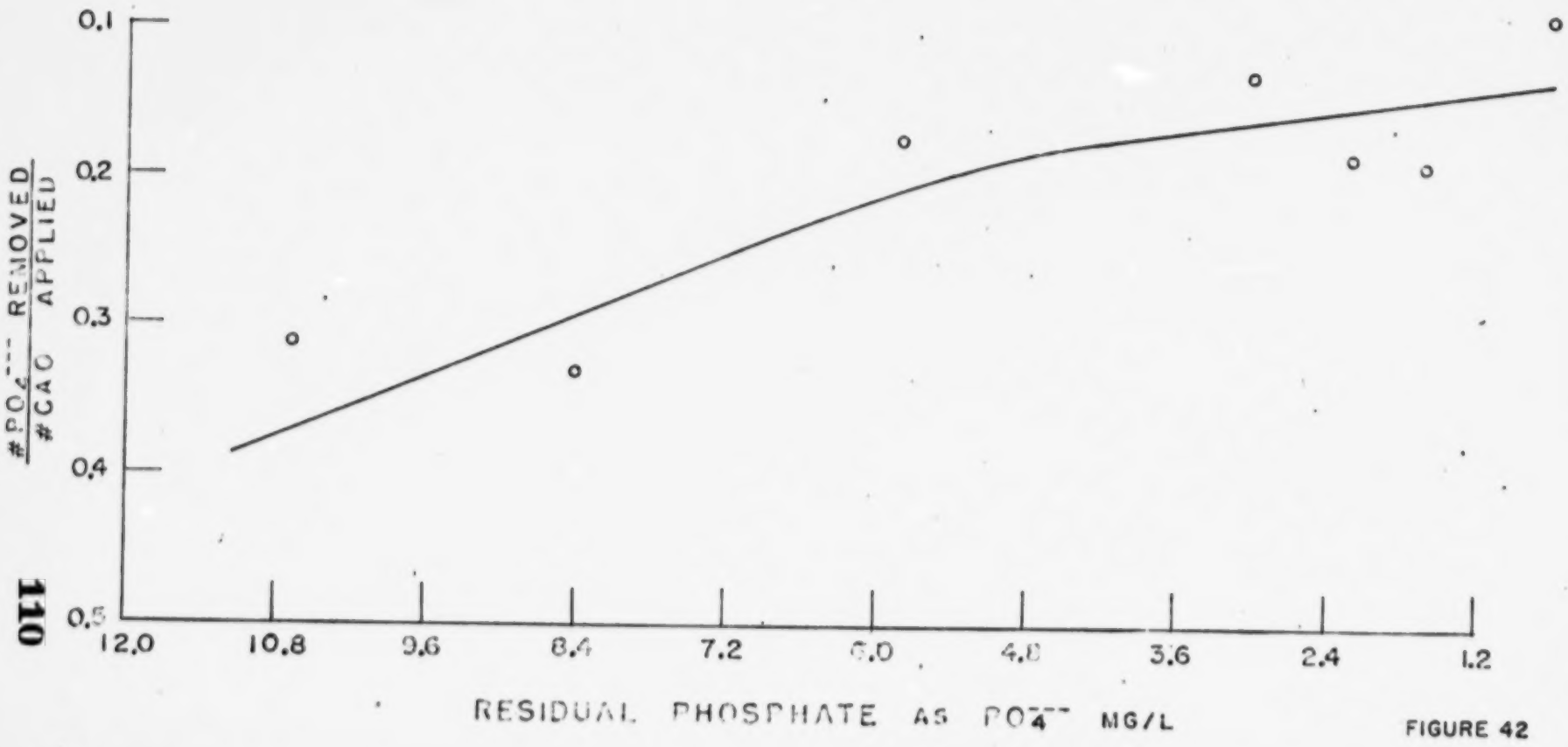


FIGURE 42

PHOSPHATE RESIDUAL vs. RATIO OF PO_4^{---} REMOVED TO CaO APPLIED

FERRIC SULFATE FLOCCULANT AID

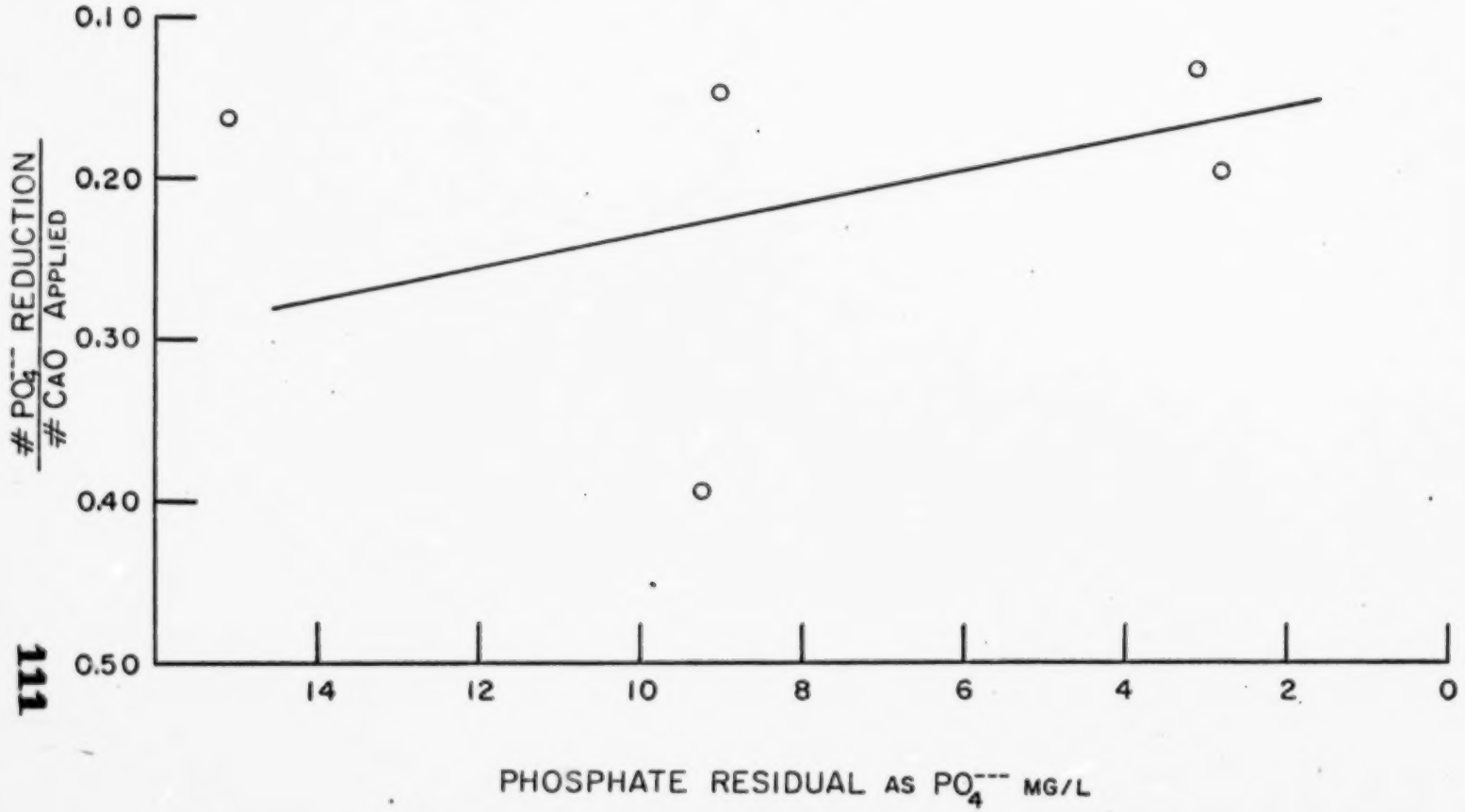


FIGURE 43

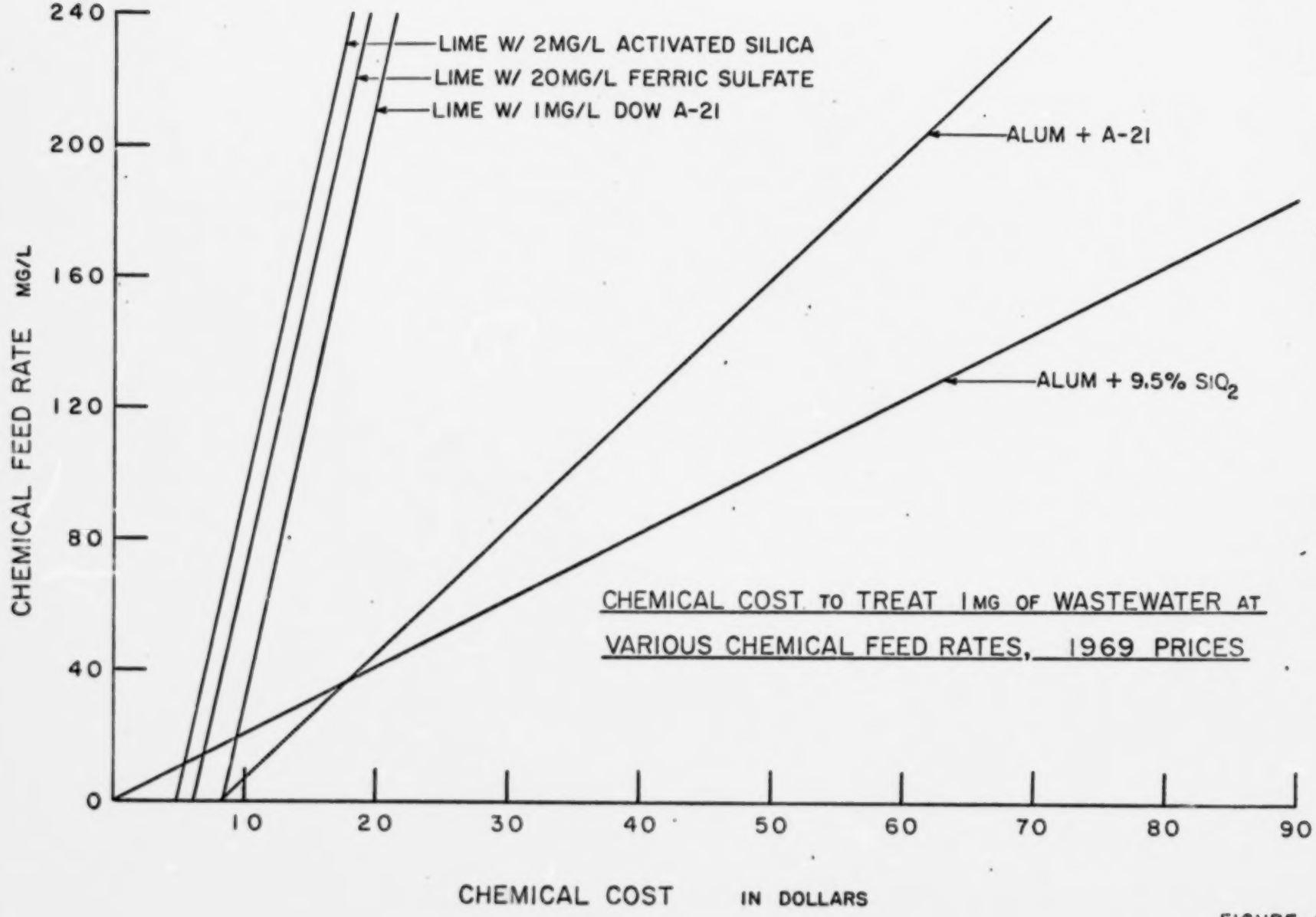

240
200
160
120
80
40
0
CHEMICAL FEED RATE MG/L
LIME W/ 2MG/L ACTIVATED SILICA
LIME W/ 20MG/L FERRIC SULFATE
LIME W/ 1MG/L DOW A-21
ALUM + A-21
ALUM + 9.5% SiO_2
CHEMICAL COST TO TREAT 1MG OF WASTEWATER AT
VARIOUS CHEMICAL FEED RATES, 1969 PRICES
10
20
30
40
50
60
70
80
90
CHEMICAL COST IN DOLLARS

FIGURE 44

APPENDIX B

OHIO WATER POLLUTION CONTROL BOARD

STREAM WATER QUALITY CRITERIA

AND STANDARDS FOR THE GREAT MIAMI RIVER

- EXERPTS -

RESOLUTION REGARDING AMENDED CRITERIA OF STREAM-WATER QUALITY FOR VARIOUS USES ADOPTED BY THE BOARD ON OCTOBER 10, 1967

MINIMUM CONDITIONS APPLICABLE TO ALL WATERS AT ALL PLACES AND AT ALL TIMES

1. Free from substances attributable to municipal, industrial or other discharges, or agricultural practices that will settle to form putrescent or otherwise objectionable sludge deposits.

2. Free from floating debris, oil, scum and other floating materials attributable to municipal, industrial or other discharges, or agricultural practices in amounts sufficient to be unsightly or deleterious.

3. Free from materials attributable to municipal, industrial or other discharges, or agricultural practices producing color, odor or other conditions in such degree as to create a nuisance.

4. Free from substances attributable to municipal, industrial or other discharges, or agricultural practices in concentrations or combinations which are toxic or harmful to human, animal, plant or aquatic life.

STREAM-QUALITY CRITERIA

FOR PUBLIC WATER SUPPLY

The following criteria are for evaluation of stream quality at the point at which water is withdrawn for treatment and distribution as a potable supply:

1. Bacteria: Coliform group not to exceed 5,000 per 100 ml as a monthly average value (either MPN or MF count); nor exceed this number in more than 20 percent of the samples examined during any month; nor exceed 20,000 per 100 ml in more than five percent of such samples.

2. Threshold-odor Number: Not to exceed 24 (at 60 deg. C.) as a daily average.

3. Dissolved solids: Not to exceed 500 mg/l as a monthly average value, nor exceed 750 mg/l at any time.

4. Radioactivity: Gross beta activity not to exceed 1,000 picocuries per liter (pCi/l), nor shall activity from dissolved strontium-90 exceed 10 pCi/l, nor shall activity from dissolved alpha emitters exceed 3 pCi/l.

5. Chemical constituents: Not to exceed the following specified concentrations at any time:

Constituent	Concentration (mg/l)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium (hexavalent)	0.05
Cyanide	0.025
Fluoride	1.0
Lead	0.05
Selenium	0.01
Silver	0.05

FOR INDUSTRIAL WATER SUPPLY

The following criteria are applicable to stream water at the point at which the water is withdrawn for use (either with or without treatment) for industrial cooling and processing:

1. Dissolved oxygen: Not less than 2.0 mg/l as a daily-average value, nor less than 1.0 mg/l at any time.

2. pH: Not less than 5.0 nor greater than 9.0 at any time.

3. Temperature: Not to exceed 95 deg. F. at any time.

4. Dissolved solids: Not to exceed 750 mg/l as a monthly average value, nor exceed 1,000 mg/l at any time.

FOR AQUATIC LIFE A

The following criteria are for evaluation of conditions for the maintenance of a well-balanced, warm-water fish population. They are applicable at any point in the stream except for areas immediately adjacent to outfalls. In such areas cognizance will be given to opportunities for the admixture of waste effluents with stream water:

1. Dissolved oxygen: Not less than 5.0 mg/l during at least 16 hours of any 24 hour period, nor less than 3.0 mg/l at any time.

2. pH: No values below 5.0 nor above 9.0, and daily average (or median) values preferably between 6.5 and 8.5.

3. Temperature. Not to exceed 93 deg. F. at any time during the months of May through November, and not to exceed 73 deg. F. at any time during the months of December through April.

4. Toxic substances: Not to exceed one-tenth of the 48-hour median tolerance limit, except that other limiting concentrations may be used in specific cases when justified on the basis of available evidence and approved by the appropriate regulatory agency.

FOR AQUATIC LIFE B

The following criteria are for evaluation of conditions for the maintenance of desirable biological growths and, in limited stretches of a stream, for permitting the passage of fish through the waters, except for areas immediately adjacent to outfalls. In such areas cognizance will be given to opportunities for admixture of effluents with stream water:

1. Dissolved oxygen: Not less than 2.0 mg/l as a daily-average value, nor less than 1.0 mg/l at any time.

2. pH: Not less than 5.0 nor greater than 9.0 at any time.

3. Temperature: Not to exceed 95 deg. F. at any time.

4. Toxic substances: Not to exceed one-tenth of the 48-hour median tolerance limit, except that other limiting concentrations may be used in specific cases when justified on the basis of available evidence and approved by the appropriate regulatory agency.

FOR RECREATION

The following criterion is for evaluation of conditions at any point in waters designated to be used for recreational purposes, including such water-contact activities as swimming and water skiing:

Bacteria: Coliform group not to exceed 1,000 per 100 ml as a monthly average value (either MPN or MF count); nor exceed this number in more than 20 percent of the samples examined during any month; nor exceed 2,400 per 100 ml (MPN or MF count) on any day.

FOR AGRICULTURAL USE AND STOCK WATERING

The following criteria are applicable for the evaluation of stream quality at places where water is withdrawn for agricultural use or stock-watering purposes:

1. Free from substances attributable to municipal, industrial or other discharges, or agricultural practices that will settle to form putrescent or other wise objectionable sludge deposits.

2. Free from floating debris, oil, scum and other floating materials attributable to municipal, industrial or other discharges, or agricultural practices in amounts sufficient to be unsightly or deleterious.

3. Free from materials attributable to municipal, industrial or other discharges, or agricultural practices producing color, odor or other conditions in such degree as to create a nuisance.

4. Free from substances attributable to municipal, industrial, or other discharges or agricultural practices in concentrations or combinations which are toxic or harmful to human, animal, plant or aquatic life.

WATER QUALITY STANDARDS ADOPTED BY THE BOARD JUNE 13, 1967,
FOR THE GREAT MIAMI, WHITEWATER, AND WABASH RIVER BASINS

The Ohio Water Pollution Control Board hereby adopts water quality standards for the following interstate waters:

(1) The Great Miami River from Dayton to the Ohio-Indiana state line and from the Ohio-Indiana state line to the Ohio River;

(2) The Whitewater River from the Ohio-Indiana state line to the Great Miami River, and the tributaries of the Whitewater River from their origin in Ohio to the Ohio-Indiana state line; and,

(3) The Wabash River and its tributaries from their origin in Ohio to the Ohio-Indiana state line.

Further, the Ohio Water Pollution Control Board hereby adopts water quality standards for the intrastate tributaries of the main stem of the Great Miami River which includes the Great Miami River, the Stillwater River, and the Mad River and their tributaries, all of which are above Dayton.

Water Quality - Conditions and Criteria

Stream-Water Quality Criteria for Various Uses adopted by the Ohio Water Pollution Control Board on June 14, 1966, shall apply to all waters under consideration herein, and, in addition, the following criteria for cold-water fisheries shall apply:

(1) Dissolved Oxygen - minimum 6 mg/l

(2) Temperature - maximum 70° F.

(3) pH - not less than 6.5 nor greater than 8.5 at any time.

The Great Miami River (1) from Dayton to the Ohio River, (2) above Dayton, and (3) all of its tributaries, shall meet the stream-water quality conditions adopted herein, and criteria for all uses adopted on June 14, 1966.

The Mad River and its tributaries above the city of Urbana shall, in addition to the above, meet the criteria for cold-water fisheries adopted herein.

The Whitewater River and its tributaries shall meet the stream-water quality conditions adopted herein, and criteria for all uses adopted on June 14, 1966.

The Wabash River and its tributaries including Mississinewa Creek shall meet the stream-water quality conditions adopted herein, and criteria for all uses adopted on June 14, 1966.

IMPLEMENTATION AND ENFORCEMENT PLAN

The Ohio Water Pollution Control Board, under the provision of Sections 6111.01 to 6111.03, 6111.31 to 6111.38, and 6111.99, Ohio Revised Code, has authority to control, prevent, and abate pollution in the waters of this state. In accordance with such authority, the Board hereby adopts the following program and requirements for the prevention, control, and abatement of new or existing pollution of the waters of the state considered herein:

(1) The design or critical flow defined as the minimum annual seven consecutive day warm weather flow which is exceeded in 80% of the years will be used in applying the stream-water quality criteria;

(2) All plans and proposals for abatement or correction of pollution will be approved by the Ohio Department of Health as required by law and such approvals shall constitute approval by the Board;

(3) All sewage will be given secondary treatment (biochemical oxidation), and the facilities to provide such treatment will be constructed and placed in operation without delay, and in no instance later than the dates specified in the attached schedules;

(4) All effluents will be satisfactorily disinfected to meet the criteria for downstream water uses and the facilities to provide such disinfection will be installed without delay;

(5) All organic industrial wastes will be given secondary treatment and other constituents will be adequately treated to meet the water quality conditions and criteria, and the facilities to provide such treatment will be constructed and placed in operation without delay, and in no instance later than the dates specified in the attached schedules;

(6) Local programs will be initiated to control and reduce pollution resulting from (a) bypassing, (b) spillages, and (c) discharges resulting from construction or breakdowns;

(7) Necessary studies will be made and, where feasible, plans and construction programs will be developed as rapidly as possible for reducing pollution from existing combined sewer overflows;

(8) Where necessary to improve water quality and to reduce algal growths, supplementary treatment of wastewaters will be provided to the fullest extent consistent with current research and technological advances;

(9) The comprehensive program for improvement of stream-water quality in the Great Miami River now being developed by the Miami Conservancy District in cooperation with local, state, and federal agencies is hereby made a part of this program; prompt implementation of this program will be necessary to fully meet the water quality conditions and criteria which should be accomplished not later than January 1, 1972;

(10) Ohio's stream-water quality monitoring program will be expanded as outlined in the attached report to adequately provide assurances of compliance with these standards.

APPENDIX C

LABORATORY PROCEDURE

FOR TOTAL PHOSPHATE DETERMINATION

LABORATORY PROCEDURE FOR TOTAL PHOSPHATE DETERMINATION

Add 2.0 ml of standard sulfuric acid solution (per Standard Methods, 12th Edition, p. 232) to 50 ml of unfiltered sample and boil gently for 1½ hours.

Cool and add 2.0 ml of ammonium molybdate solution (per Standard Methods, 12th Edition, p. 235) and mix.

Add 0.25 ml stannous chloride solution (per Standard Methods, 12th Edition, p. 235).

Transfer to 50 ml Nessler tube and make up to 50 ml using distilled water.

Allow to stand for 20 minutes and determine color intensity at a wavelength of 690 mu using a Bausch & Lomb Spectronic 20.